PQstorI Grid Code functionality manual

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Contents

1 Introduction

This technical document describes the grid code functionality of the PQstorI module and associated system level PQpluS. There are a large number of parameters that are available within the structure of the code. This is intended to accommodate a wide range of different grid code requirements and as such for each grid code, only a small portion of these will be set at any one time through the use of grid code profiles. Furthermore, the implementation uses the data models described in [3].

This document will explain the use of all available grid functions that have been implemented in the firmware. Particular emphasis is made on VDE-AR-N 4105 and 4110 ([1] and [2]) being widely recognized within Europe. In spite of this it has been the IEC 61850-90-7 standard (part of a series for power utility automation) that has been used as the guide for the creation of the various grid code functions.

2 Version details

2.1 Software

The PQstorI described in this document is covered by the following uP and DSP versions. Earlier versions of uP and DSP have been covered by previous Certifications.

Table 1 – uP and DSP version history

Device ID	Version Number
µP	V1.0 rev 20
DSP	V56.2 rev 77

3 Hardware requirements

3.1 Block Diagram of the PQstorI

The block diagram of Figure 1 shows the various hardware stages of the PQstorI inverter in order to connect between the grid and a DC source while controlling voltage and frequency in order to support the grid and the customer needs. This includes the AC and DC fuse protection as well as connection/disconnection relays/contactors. As part of the start-up sequence there are both AC and DC pre-charge circuits which are then bypassed by the internal relays/contactors once predefined conditions have been met. This thus results in a few seconds delay from a READY or STANDBY state to a RUN state. For this reason the normal state for this grid connected inverter is RUN state in order to be able to respond quickly in supporting the grid and meeting the requirements of the customer.

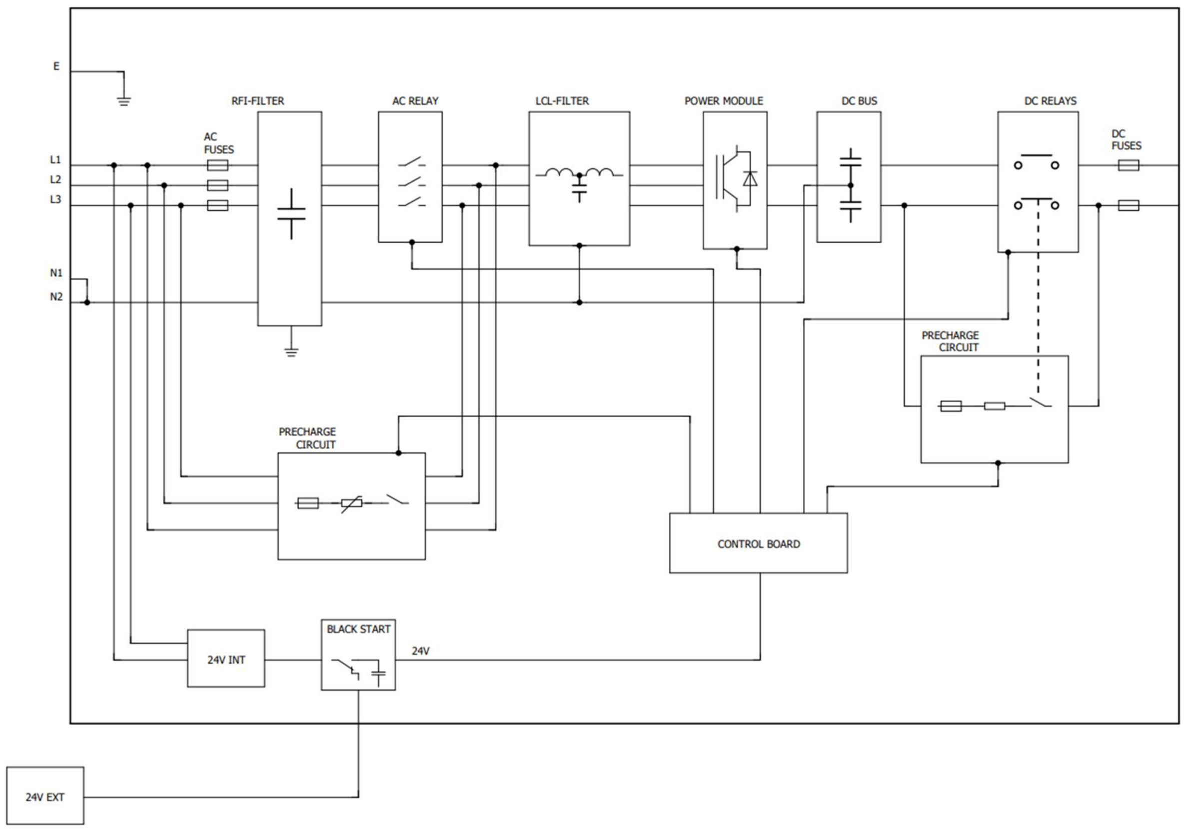


Figure 1 – Block diagram of the PQstorI

An additional critical requirement for grid connected inverters is the ability to ride through dips (down to zero) of the mains voltage. This is provided by the so called "black-start" circuit that serves two functions. The first is to provide an energy source for the control board to enable the inverter to ride through these low voltage interruptions. The second purpose is to provide additional external interface. These include the following (refer to Figure 2):

11. Measurement of 1ph AC voltage across a main grid disconnect contactor/breaker

12. Output to control the main grid disconnect contactor/breaker

13. Emergency stop input to enable tripping of the inverter once a 24V control circuit has been interrupted

14. Input for optional external 24V supply

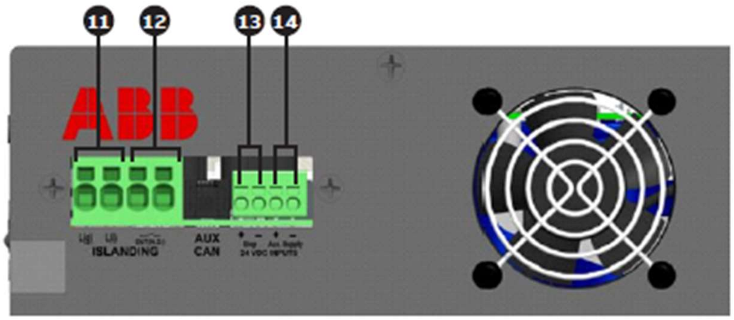


Figure 2 – Blackstart PCBA interface terminals

3.2 NS-Protection Relay

Though the PQstorI includes grid code protection functions, it does not have the hardware at present to measure up-steam of the main disconnector. Thus, in order to meet the protection requirements of the grid codes, the PQstorI is required to be used in conjunction with a suitably recognized NS-Protection relay. Two examples that can be used are:

- ABB - CM-UFD.M33
- ZIEHL - UFR1001E

An example wiring diagram showing the interconnection between these is shown in Figure 3.

When the NS-Protection trips or detects a fault with the main disconnection device, it provides a fail-safe (active low) signal to the PQstorI to trip. Due to the fact that the PQstorI does not include reconnection functionality, it would typically be setup with automatic reconnection. This means it will reconnect when the NS-protection signal is returned to a high state.

In the case of multiple inverter installations, all the interconnections between each module, are connected in parallel. This ensures that all modules will have 24V input applied to them for the Emergency stop signal. In the case of an Island trip signal, any one of the inverters can trigger the disconnection of the Grid interconnection switch.

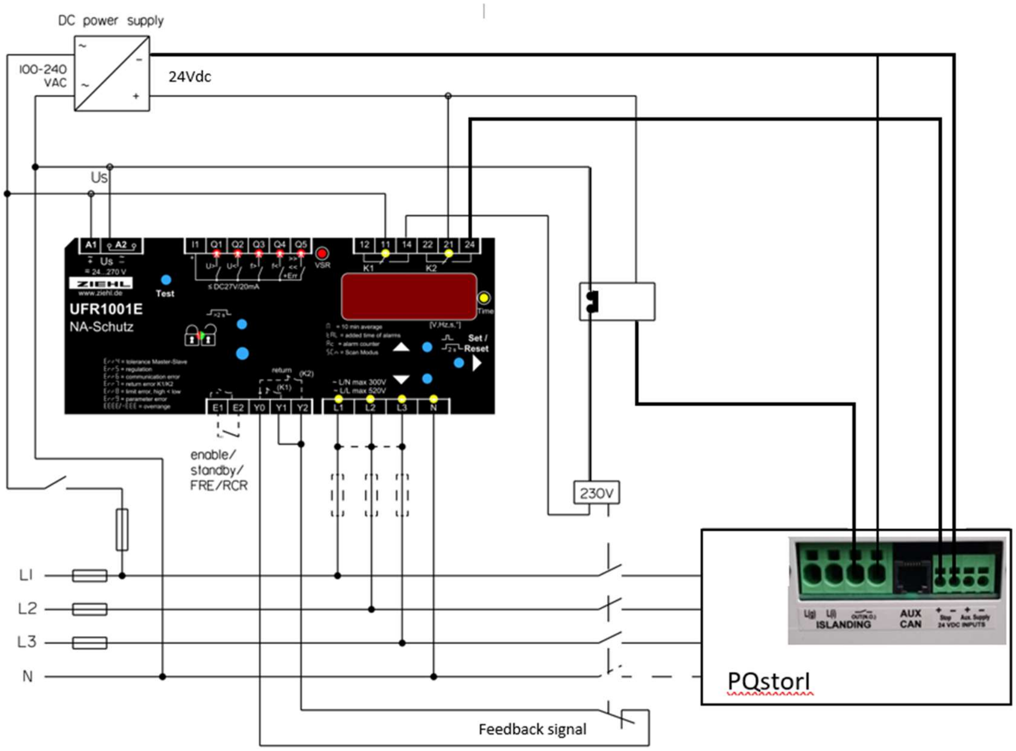


Figure 3 – Example NS-Protection relay interconnection diagram

4 Techincal Specifications

Table 2 – PQstorI specifications

Specifications	PQstorI – M (module)	PQstorI – WM (Wall-mounted)	PQstorI – C (Standalone cabinet)
Electrical characteristics			
Connection method	AC grid tied connection side - 3P3W+PE		
Network voltage (+/ - 10%)	208 - 415 V		
Network frequency (+/ - 5%)	50/60Hz		
Rated power (at 400 V)	30 kW		
Line current rating per Base unit (A)	43 A		Full cubicle: 43 A … 688 A
DC Energy source connection side			
DC voltage (min)	590 V for 3 W application (**note 1**)		
DC voltage (max)	830 V (890 V with reduced power)		
DC current	52A		
Environmental specifications			
Ambient temperature	-10°C to 50°C with thermal-derating (**note 2**)		
Storage temperature	-25°C to 70°C during storage		
Cooling	Forced air ventilation (replaceable fans)		
Humidity	Max. 95% non-condensing during operation Max. 85% non-condensing during storage		
Pollution Degree	PD2		
Overvoltage Category	OVC III (AC) OVC II (DC)		
Altitude	Indoor installation in clean environment at 1000m (upto 5000m with derating)		
IP protection	IP20 from front access	IP30	IP21
Noise	< 61dB @ 1m		
Performance specifications			
Efficiency	typically 98%		
Equipment losses	<2% of the equipment power typically		
Voltage accuracy	< ± 1%		
Output THDi	≤ 3%		
Power factor	1 to -1, capacitive to inductive, continuously adjustable		
Frequency accuracy	< ± 0.01Hz		
Power accuracy	< ± 2% kW/kVar		
Overload capability	None		
Inverter technology	Three level inverter		
Switching frequency of semiconductors	18 kHz		
Parallel operation	Up to 16 modules can be combined. Different module ratings are allowed		
Redundancy	Any unit can become a master (defined as the lowest ID that is operational). In case of failure, other unit takes the lead as master		

Specifications	PQstorI – M (module)	PQstorI – WM (Wall-mounted)	PQstorI – C (Standalone cabinet)
Interface / communication			
Wi-Fi communication	Webserver on smartphone or computer for simple diagnostics and parameters setup		
USB	With dedicated optional software (servicing/ programming)		
RJ12	For CAN bus communication between HMI and other modules		
CT inputs	3 ph CT measurements (class 1.0 or better, 15 VA)		
2x 24Vdc inputs	1 for Emergency stop 1 for external supply		
230Vac Relay output	For control of external grid contactor/breaker		
Wi-Fi communication	Webserver on smartphone or computer for simple diagnostics and parameters setup		
PQconnecT	Dimensions (W x D x H)	78 x 25 x 94 mm	
	IP protection	IP 20	
	Communications	CAN: RJ12 - 500 kbit/s or 1 Mbit/s Ethernet: 10/100 Mbit, full or half-duplex, HP Auto-MDIX support	
	I/O	1 relay output, normally open, 5 A / 30 VDC	
PQoptiM (optional)	7-inch color TFT screen (800 x 480 pixels)		
	Dimensions (W x D x H)	198 x 141 x 40 mm	
	IP protection	IP65 front side / IP 20 backside	
	Communications	CAN 2B (internal) – RJ12 Ethernet (Modbus TCP) – RJ45 USB 2.0	
	Digital I/O on HMI	2 insulated digital inputs - +24 V (AC or DC) 6 digital NO outputs – 250 Vac/ 5 A (one common polarity), dry contacts	
Mechanical aspects			
Mounting Dimensions (W x D x H)	Modules, suitable to integrate into a cabinet on draws or as part of a rack system with push connectors 435 x 459 x 130 mm	Wall-mounted 438 x 199 x 517 mm	Free standing cabinet 600 x 800 x 2100 mm
Color		Surface treated metal frames HMI holder painted RAL 7035	RAL 7035
Fixation	Special kit allows module to be integrated into cabinet	via wall-mounting kit	Floor fixation/ lifting
Cable entry	Rear for power cables Front for control cables	Top for power cables Bottom for control cables	Bottom for both power and control cables

[1] Limited high voltage ride through support at lower DC voltages (See PQstorI Instruction Manual)

2 The derating will depend on the DC voltage level that exists on the bus (See PQstorI Instruction Manual)

5 Inverter Capability Curve

5.1 PQ Capability Curve

The PQstorI PQ capability curve is shown in Figure 4. This demonstrates the reactive power (Q) support capability with respect to the real power (P) level for 7 different grid voltage levels (per unit values of 0.85, 0.9, 0.95, 1.0, 1.05, 1.1 and 1.15). Since there is no overload capability within the PQstorI, all the curves above nominal have the same results as that at nominal voltage.

The partial table of the associated datapoints, are included in Appendix E – PQ capability curve table of data. The full data record can be supplied separately when required.

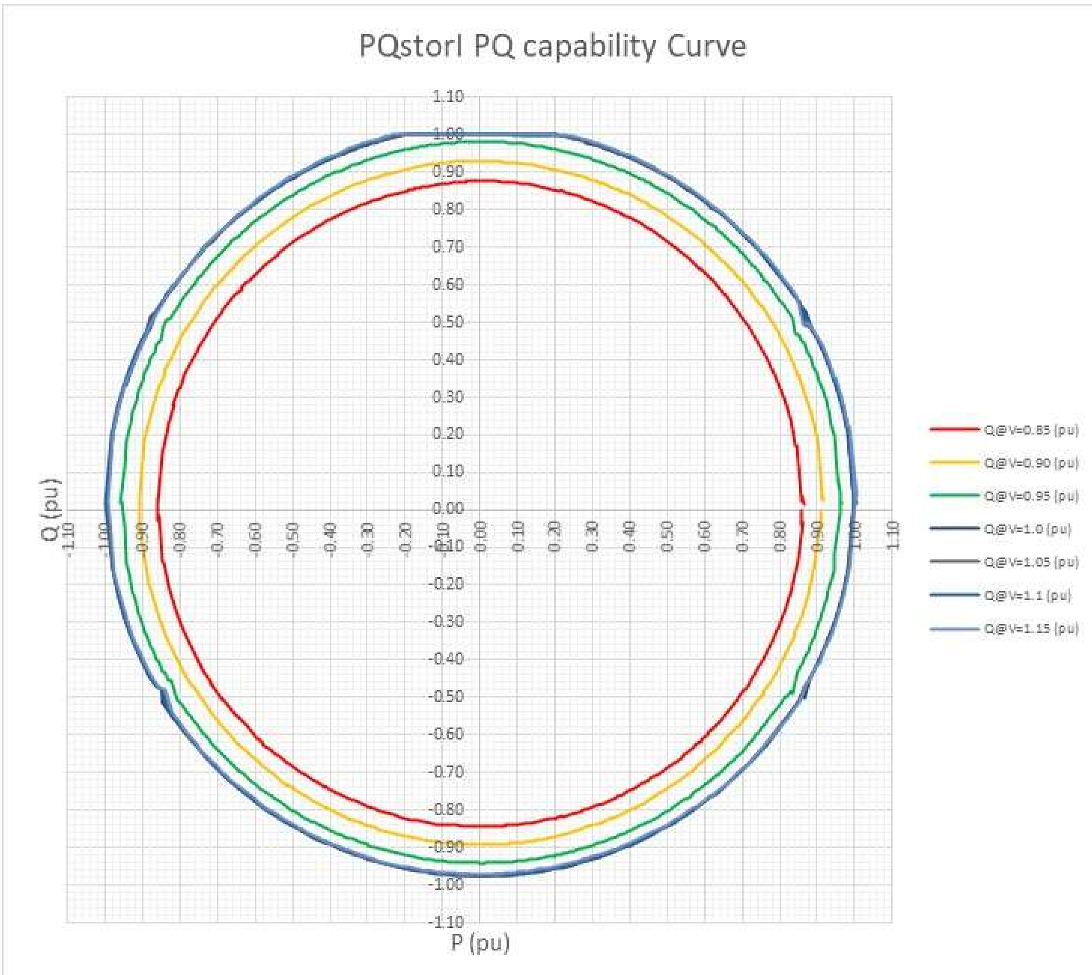


Figure 4 – PQ Capability curve for the PQstorI module (in per units)

6 Grid Code Profile

For each individual grid code, there will need to be a grid code profile created. Each profile consists of a number of functions for which there are a number of parameters. The enabling of these functions and the appropriate settings are determined by the grid code applicable for the location of the installation, also directed by the DSO. Each function will be individually described in the following sections.

Not all parameters can be accessed by all users. Only users in possession of the PRIVATE KEY (See [4]), for the corresponding access level can modify parameters. Access levels are listed in Table 3. The various parameters are populated using an appropriate “profile” table which is created using a Profile manager tool a capture of which is shown in Figure 27 (refer to [4]).

The parameters of access level 1 through 3 can only be accessed using the appropriate tool. They can only be changed as part of a profile while the equipment is stopped.

The parameters of access level 4 and 5 can be accessed through the Modbus TCP interface using any compatible tool such as an HMI or PQconnecT. These parameters can be changed at any time (except the anti-islanding Parameter) while the equipment is running.

The Modbus table with register information is available separately.

Table 3 – Access Levels

Access Level	Group	Memory Type
1	Validation Testing, Certification, Utility*	Flash
2		Flash
3		Flash
4	Utility, Integrator / Commissioning	EEPROM
5	End User	RAM

*It should also be realized that during the commissioning stage, the utility may also request some of the parameters in levels 1-3 to be altered hence requiring a change to the original profile.

Parameters that are common to most functions are shown in Table 4. As with all the parameter tables that follow, the values presented are not necessarily default values. These will be set as part of the particular grid code profile selected for the installation sight.

The final settings for these parameters are set as part of the specific site / DSO requirements during the commissioning and final system Certification. These changes will then need to be recorded as a new profile specific for that installation at that time.

Table 4 - Common Parameters

Parameter	Description	Range	Default	Access Level
MaxWLim	Nominal max output power at controller or ECP (kW)	10.0 to 120.0	30	1
MaxVArLim	Nominal max output reactive power at controller or ECP (kVar)	10.0 to 120.0	30	1
WMax	Setting for maximum active power and reference value for functions (kW)	10.0 to 120.0	30	1
VArMax	Setpoint for maximum reactive power (kVar)	10.0 to 120.0	30	1
VRef	Reference voltage for functions using grid voltage as input (V)	10 to 690	400	1
DERNum	Number of DER units connected to controller or number of units	0 to 16	1	4
PrampMax	Applied during reconnection and INV4. Power gradients at a maximum rate of x % PAmax (WMax) per second (puW/s).	0.0001 to 1.0	0.0066	4
PrampAltMax	Alternative ramp rate applied to fSet_P for application purposes. Power gradients at a maximum rate of x % PAmax (WMax) per second (puW/s).	0.0001 to 1.0	1	4
ReconnRmpUp_ModEna	Reconnection ramp enable	0 or 1	0	4

7 Reactive Power Management

The following functions are implemented to satisfy reactive power requirements per [1] and [2]. The functions are controlled by the parameters shown in Table 5 which are organized specifically to meet the VDE requirements. There are though, very similar grid code functions that exist and explained in later sections. They are described individually in later sections. Only one of the parallel functions can be enabled at any one time. It is up to the commissioning engineer to determine which functions to select as appropriate for the installation site and the requirements of the DSO.

0. Fixed Q value
1. Reactive power with voltage limiting function - [VV11, section 11.3]
2. Reactive power voltage characteristic curve Q(U) - [VV12, section 11.3]
3. Displacement factor cos ϕ – [INV3, section 11.1]
4. Reactive power versus Active power curve Q(P) – [WP41, section 11.4]

In all these modes (except mode 0), Var is given priority over Watts.

Table 5 – Parameters for reactive power management

Parameter	Description	Range	Default	Access level
VDE_Ctrl_ModEna	Selects one of five modes 0 = Disabled – enables fixed Q setpoint 1 = Voltage limiting function 2 = Q(U) curve 3 = Displacement factor cos ϕ 4 = Q(P) curve	0, 1, 2, 3 or 4	0	4
VDE_Ctrl_QRef	Set-point reference reactive power (pu)	-1.0 to 1.0	0.0	4
VDE_Ctrl_UQ0	Default reference voltage (pu)	0.05 to 1.2	1.0	4
VDE_Ctrl_cos_phi	Target power factor. Positive values represent an inductive power factor.	-1.0 to -0.6, 0.6 to 1.0	-0.93	4
VDE_3TauPT1Tms	This allows for a damped response to changes in the Q as shown in Figure 5 (s)	0 to 60	0	4
UserVarPriority	Var Priority control. High indicates that Var will have priority over W when there is no other overriding automatic function in operation	0 or 1	0	4
UQO_Deadband	Q(U) curve (mode 2/VV12) voltage deadband (pu)	0.0 to 0.05	0.01	4
SetQp_3TauPT1Tms	This allows for a damped response (PT1) to changes in the Fixed Q setpoint in mode 0.	0.0 to 60.0	0	4

When there is a change in setpoint of Q as a result of the operation of these listed functions, the new Q value will be reached following the PT1 behavior shown in Figure 5 with the 3Tau value defined by the parameter VDE_3TauPT1Tms. This applies in the case of voltage, Power, switching between modes and changing of various references such as VDE_Ctrl_QRef, VDE_Ctrl_UQ0 and VDE_Ctrl_cos_phi.

In Mode 0 there is a separate PT1 setting (SetQp_3TauPT1Tms) to changes in setpoint thus enabling the end customer the ability to respond to fast changes in the load.

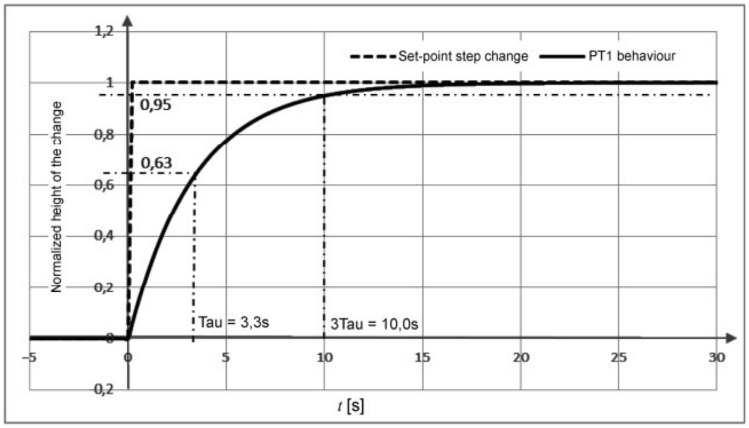


Figure 5 - Example of the control behavior in the event of an abrupt change in Q

7.1 Fixed Q Mode

To apply a fixed reactive power setpoint without any automatic response to voltage variations proceed as follows (A fixed value of Q is not able to be set if VDE_Ctrl_ModEna is anything other than zero).

1. Set VDE_Ctrl_ModEna = 0
2. Set fSetQp to the target reactive power in kVAr using the Modbus interface or the HMI
3. UserVarPriority can be set to 1 to enable VAR priority over WATTS.
4. SetQp_3TauPT1Tms usually set as part of the grid code profile

Any setpoint changes in Q under this mode follow PT1 behavior shown in Figure 5 according to the SetQp_3TauPT1Tms setting. In order for the end user to respond to fast load changes, this PT1 value will need to be set to zero. The coordination between the PT1 setting and fSetQp will need to be closely controlled via the EMS (Energy Management System) in order that the reactive power changes seen at the PCC follow the PT1 response as determined by the DSO.

7.2 Reactive power with voltage limiting function

This function combines a user-defined set point for the reactive power with volt-var support. As such the function is similar although not identical to VV11 described in section 11.3. An example is shown in Figure 6 (refer Appendix A: Direction definition of P and Q).

The reactive power varies automatically with the variation in voltage according to a curve defined by a point array. Where VDE_Ctrl_QRef is anything other than zero (as demonstrated using the dashed line) the points P1 and P2 move together along the slopes. Presently for this function, the VDE_Ctrl_QRef is linked specifically to points P1 and P2 for this function to respond correctly.

See section 8.2.1 for an explanation of point arrays.

To use this function

1. Set VDE_Ctrl_ModEna = 1
2. Set the parameters of VV11
3. Ensure that VV11_DeptRef = 2 for VArs as percent of maximum vars (VArMax)
4. Define number of points appropriate for your curve (for the example shown in Figure 6 this would be 4 points).
5. Set VDE_Ctrl_QRef to required pu value

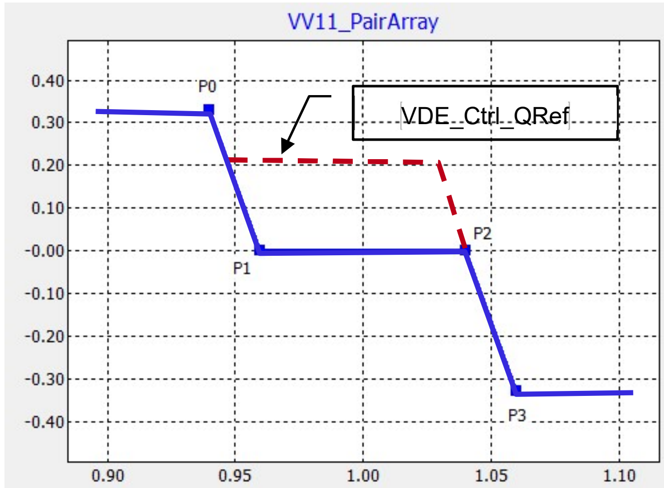


Figure 6 – Example of reactive power with voltage limiting function

7.3 Q(U) Curve

When selected (VDE_Ctrl_ModEna = 2), the function injects reactive power in response to varying voltages similar to the function described in section 7.2. As such it is a volt-var management function similar to VV12 described in section 11.3. In fact, Q(U) is implemented using the VV12 parameters to define the point array. However, Q(U) differs from VV12 in the following way. With the change of a single parameter VDE_Ctrl_UQ0 (or UQ0 for short) the curve can be shifted along the voltage axis (as demonstrated in Figure 7 by the dashed line). If UQ0 = VRef then the curve is as defined by the point arrays of VV12.

As demonstrated with the function described in section 7.2, any desired hysteresis or additional intermediate slopes can be added using additional points in the point array.

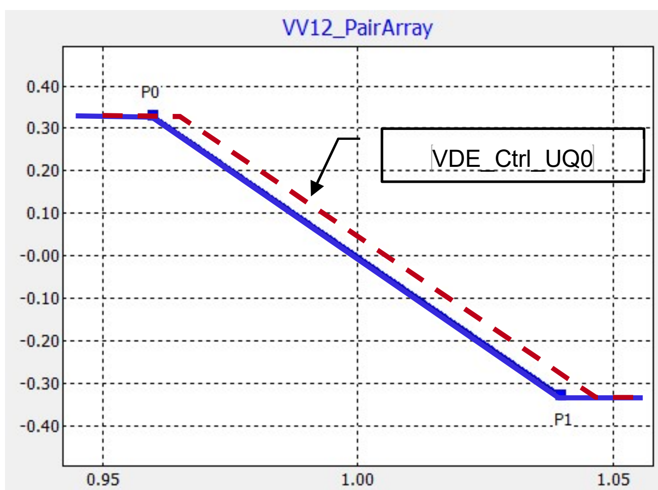


Figure 7 – Example of Q(U) characteristic curve

There is also a requirement within VDE to provide the facility for a dead-band around the voltage in order to avoid continuous changes in Q with small changes in voltage. The Figure 8 below demonstrate the performance with dead-band applied. As the voltage changes it will normally follow the characteristic curve as shown with the black line.

– At point P1, the voltage measured results in a value of Q1.

– At point P2, the voltage shift by an amount that is less than the dead-band (eg: minus 1%). This should not cause a change in the Q output.

– At Point P3 the voltage shift to a level that exceeds the positive dead-band (eg: plus 1%). This thus resulting in the applicable Q (Q2) that lies on the main characteristic curve.

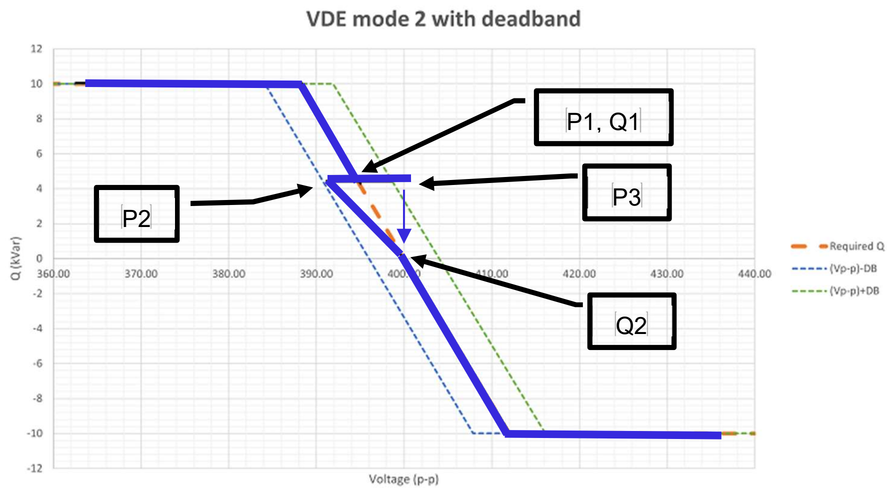


Figure 8 – Example Q(U) function with a deadband applied.

To use this function:

1. Set VDE_Ctrl_ModEna = 2
2. Set the parameters of VV12, however, ensure that VV12_DeptRef = 2 for VArs as percent of maximum vars (VArMax)
3. Define only two points (P1 and P2) similar to Figure 7 (refer to Appendix A: Direction definition of P and Q). The horizontal segments are implied.
4. Set VDE_Ctrl_UQ0 to the required zero crossing point.
5. Set applicable dead-band as communicated by the DSO.

7.4 Displacement factor cos φ

The objective of the displacement factor control is to enable the power generating plant to feed in power with a constant active power/reactive power ratio into the network.

(For another function which is very similar to this, refer to section 11.1).

To use this function:

1. Set VDE_Ctrl_ModEna = 3
2. Set VDE_Ctrl_cos_phi to the target power factor (positive for inductive, negative for capacitive)

7.5 Q(P) Curve

When selected (VDE_Ctrl_ModEna = 4), the function injects reactive power in response to varying active power levels. This function has its own point array similar to Table 7 except that the parameter names start with “PQ_” instead of FW22. See section 8.2.1 for an explanation of point arrays. An example of a Q(P) function is shown in Figure 9 (refer to Appendix A: Direction definition of P and Q).

(For another function which is very similar to this, refer to section 11.4 which applies a Power – PF relationship).

To use this function:

1. Set VDE_Ctrl_ModEna = 4
2. Set the parameters of PQ
3. Ensure that PQ_DeptRef = 2 for VArs as percent of maximum vars (VArMax)
4. Define as many points as required.

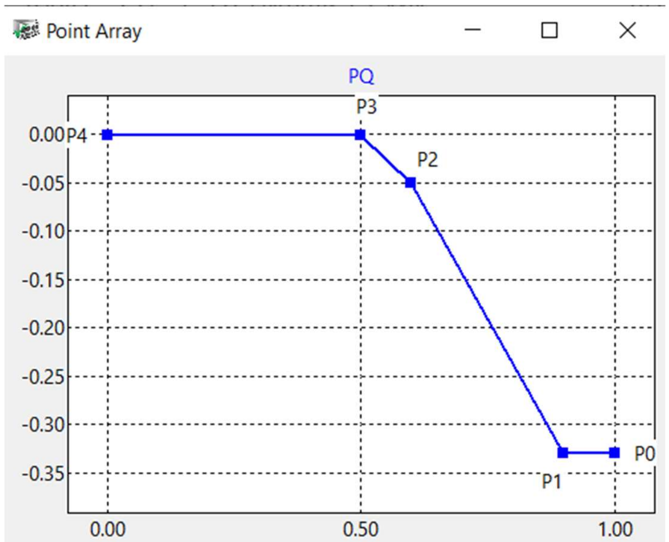


Figure 9 – Example of Q(P) characteristic.

8 Active Power Management

8.1 Active power demand modes

8.1.1 (fSet_P)

A fixed active power output can be set either directly in kW or as a fraction of the maximum wattage (WMax). To use this mode either set fSet_P to the target power output using the Modbus interface or HMI. Positive values indicate discharging and negative values indicate charging. This value is used for application purposes and has the fPram-pAltMax ramp applied to it during any setpoint changes.

8.1.2 INV4: request active power

Power converter-based DER systems which can manage energy production through additional generation reserve and/or storage capabilities can respond to requests to increase or decrease this energy production remotely using INV4. This function requests the storage system to charge or discharge at a specific rate (% of max charging or discharging rate). The function is controlled by the parameters listed in Table 6.

Table 6 – Parameters for INV4

Parameter	Description	Range	Default	Access level
INV4_OpModExIm	Enable set charge/discharge rate	0 or 1	1	4
INV4_OutWRte	Setpoint for charge/discharge as fraction of WMax. Allowed range is -1.0 to +1.0. Positive values indicated discharge into the grid (pu)	-1.0 to 1.0	0	4
PrampMax	Applied during reconnection and INV4. Power gradients at a maximum rate of x % PAmax (WMax) per second (puW/s).	0.0001 to 1.0	0.0066	4
PrampAltMax	Alternative ramp rate applied to fSet_P for application purposes. Power gradients at a maximum rate of x % PAmax (WMax) per second (puW/s).	0.0001 to 1.0	0	4
ReconnRmpUp_ModEna	Reconnection ramp enable	0 or 1	0	4

These functions operate in conjunction with Set_P (Power setpoint value from external controller).

Any change in INV4_OutWRte will follow the ramp PrampMax while any change in Set_P will follow PrampAltMax. The two changes will sum together.

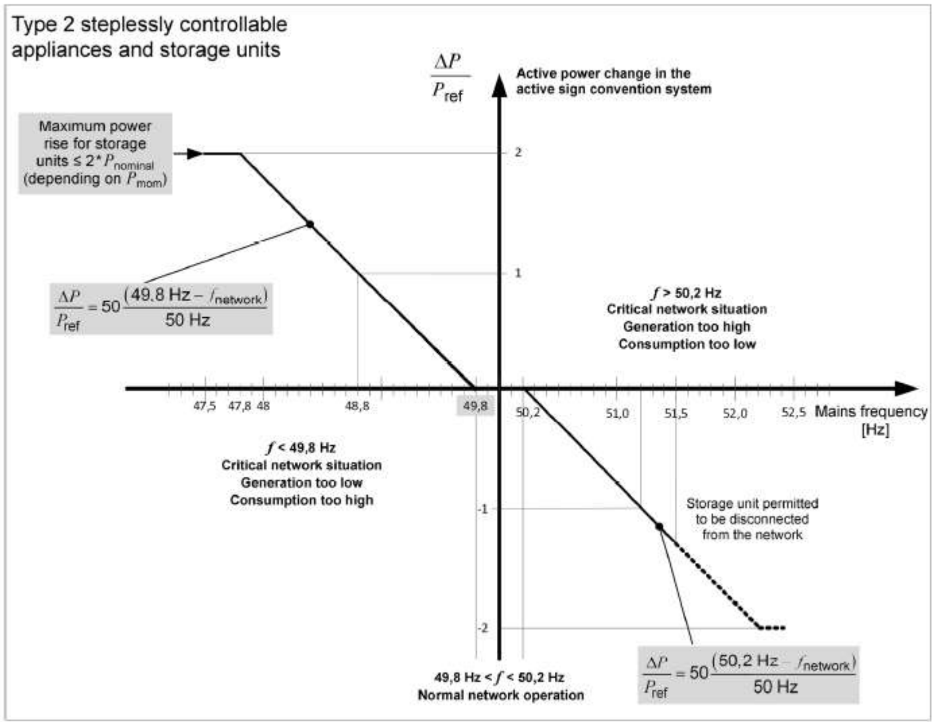
In the event of a disconnection and reconnection, any power setpoint previously set will be reached following the PrampMax if ReconnRmpUp_ModEna is set to 1.

For both the ramp parameters, if set to zero, no ramp will be applied and so any setpoint changes will be applied within less than 60ms. The ramping can be enabled from below 0.001 puW/s but a lower limit of 0.001 as been set. This represents a ramp of 0.1% WMax/s. At the other end, a maximum ramp of 1 puW/s (100% WMax/s) though this can be extended through the Grid Code Profile management tool.

8.2 Over/under frequency derating

In the case of over-frequency, there is a surplus of generation power over demand. In the case of underfrequency, a deficit in generation power is accompanied by an excess of demand. Therefore, storage units shall be able to adjust the active power working point for over-frequencies between a minimum and a maximum. The onset of this frequency dependent active power feed-in must be settable

Figure 10 shows an example of change of power output as a function of frequency. This change is added to the present value of active power, for example the user-defined active power setpoint (See section 8.1)



Key

P_{ref} corresponds to $P_{b\ inst}$ or corresponds to P_{mom}, respectively, for Type 2 power generating plants (without storage unit(s)) at the moment where 50,2 Hz is exceeded

ΔP power change

f mains frequency

Figure 10 – Example of frequency power characteristic

The function recognizes three states:

– Default state

– Critical state, outside nominal range

– Critical state, inside nominal range

While in critical state (outside the nominal range), the function does not allow other functions to increase (decrease) active power while seeking to decrease (increase) active power. For example, if the user changes the active power setpoint while in an over frequency state, the function will block the change until the frequency satisfies stable frequency conditions and the settling time requirements have been met.

8.2.1 Frequency-watt mode FW22

One of the methods of applying the automatic change in Power with change in frequency is FW22. The principle is shown in Figure 11.

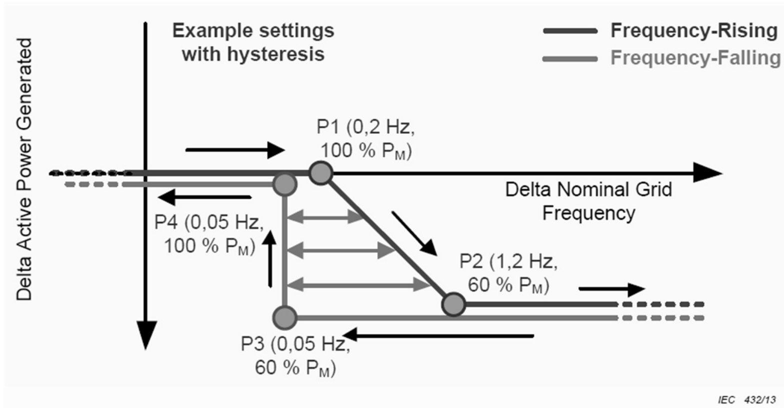


Figure 11 – Principle of FW22

To use this function:

1. Set FW22_ModEna = 2
2. Set the parameters of FW22 as desired
3. Define the point array with as many points as desired. Use of hysteresis is supported.
4. In particular, set FW22_RmpDecTmm and FW22_RmpIncTmm to the desired values, for example 0.1 for 10% of WMax per minute

In the point array the two points closest to the P-Axis define the nominal range, which is typically ±0.2 Hz but can be set at any distance from nominal. The x-values of the point array only specify the delta from the nominal frequency in Hz. Similarly, the y-values of the point array specify the delta P as a fraction of WMax.

The use of point arrays enables any form of curve to be created including hysteresis. If as shown in Figure 11, the F-values of the points change direction, then the point array is effectively treated as having two portions that enclose a region in the F/P-plane. As long as the F and P values are within the region, the output variable P is not changed. Otherwise the output variable is limited by either the upper or the lower portion of the point array. For F-values that are greater than the maximum F-value of the point array the P-value corresponding to that point (maximum F-value) is selected. For F-values that are less than the minimum F-value of the point array the P-value corresponding to that point (minimum F -value) is selected. Thereby the P-output remains flat beyond the minimum / maximum F-values.

It should be noted that FW22 adds or subtracts active power to the active power level defined by the user setpoint (Set_P) and potentially other grid code functions that output active power.

From the point when the frequency returns within nominal range (typically +/- 0.05Hz) it is still considered critical until the frequency stays in the nominal range for a settling period (FW22_StlTms typically 10 minutes). While in this critical state, the power is able to slowly ramp to a frozen setpoint (that which existed prior to the disturbance). The rate of change is limited to FW22_RmpDecTmm and FW22_RmpIncTmm.

Figure 12 shows the implementation method used within the PQstorI where the lines P4 to nominal and P0 to nominal actually represent slow ramps back to the frozen power level (Power frozen at the point at which the event occurs).

The function is controlled by the parameters listed in Table 7.

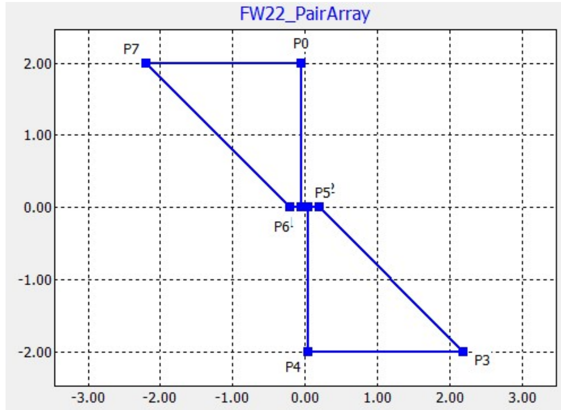


Figure 12 – Example of the method used for the PQstorI

In order to meet VDE-AR-N 4105 there is a unique requirement for energy storage inverters to ensure a hysteresis response when in charge mode. This is demonstrated in the example profile curve shown in Figure 13 below.

Using the parameter FW22_HystCharge set to 1, any over frequency event will reduce the power as per the curve. If this results in the power changing to charge mode, during recovery of the frequency disturbance, the power will follow a slow ramp (determined by FW22_RmpIncTmm) back to the pre-event value.

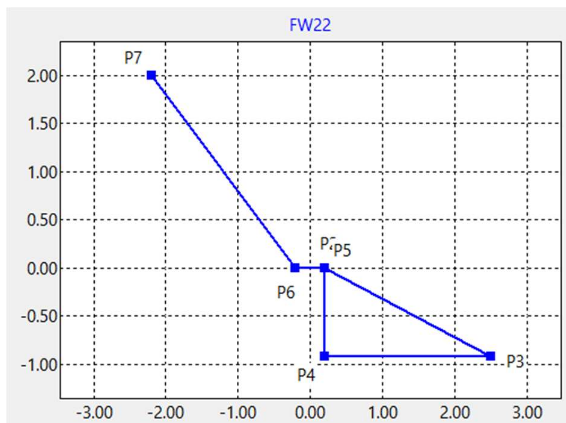


Figure 13 – Example FW22 curve for VDE 4105

Table 7 – FW22 Parameters

Parameter	Description	Range	Default	Access Level
FW22_ModEna	Enabled/disables the function	0 or 2	0	4
FW22_DeptRef	Enumeration of the independent reference parameter units using SI units 0 = Not applicable / unknown 1 = None, dimensionless 2 = VArs as % of maximum vars (VArMax) 3 = VArs as % of available vars (VArAval) 4 = VArs as % of maximum watts (WMax) 5 = Watts a % of maximum watts (WMax) 6 = Watts as % of frozen active power WRef	0 to 6	5	1
FW22_OverFreqDelay	Delay after an Overfrequency event before ramping back once frequency within threshold limits (applicable for AS-NZS 4777-2) (s)	6 to 600	6	1
FW22_UnderFreqDelay	Delay after an Underfrequency event before ramping back once frequency within threshold limits (applicable for AS-NZS 4777-2) (s)	6 to 600	6	1
FW22_RmpDecTmm	The maximum rate at which the dependent value (output) may be reduced in response to changes in the independent value (input). This is represented in terms of PU value of the Reference (e.g. WMax) per minute (puRef/min).	0 to 10.0	0.1	1
FW22_RmpIncTmm	The maximum rate at which the dependent value (output) may be increased in response to changes in the independent value (input). This is represented in terms of PU value of the Reference (e.g. WMax) per minute (puRef/min)..	0 to 10.0	0.1	1
FW22_RmpRsUp	The maximum rate at which the dependent value (output) may be increased after releasing the frozen value of snap shot function. This is represented in terms of PU value of the Reference (e.g. WMax) per minute (puRef/min)..	0 to 10.0	0	1
FW22_StlTms	Settling time under FW22 once frequency reaches nominal frequency (s)	0 to 600	600	3
FaultDelayFW22Tms	Blocking delay for FW22 response after start of a fault (ms)	0 to 5000	500	3
FW22_PairArray_NumPts	Number of points in the point array	1 to 20	8	1
FW22_PairArray_P0_xVal	Point 0, x value (Hz)	-10.0 to 10.0	-0.05	1
FW22_PairArray_P0_yVal	Point 0, y value (Ppu)	-2.0 to 2.0	2	1
[…]	[…]	[…]	[…]	
FW22_PairArray_P19_xVal	Point 19, x value (Hz)	-10.0 to 10.0	0	1
FW22_PairArray_P19_yVal	Point 19, y value (Ppu)	-2.0 to 2.0	0	1
FW22_HystCharge	This ensures a hysteresis response to over frequency changes only in charge mode	0 or 1	0	3

9 Fault Ride-Through Functions

The objective of the fault ride through functions is to prevent any unintentional disconnection of the generation power and the risk to the network stability involved in the event of short-term voltage dips or rises such as during a fault. This must support 3-phase, 2-phase and single-phase fault situations. In addition, the network could be supported with reactive current as a function of the voltage dip or rise.

9.1 Low/high voltage fault detection

A key requirement for fault ride through functionality is the identification of a fault state. There are certain thresholds that have to be set. These are listed in the Table 8 below. Once a fault is detected it is possible to enable dynamic support functions such as TV31 which provide reactive current injection (see section 9.3.1) if enabled.

The fault detection method of the PQstorI evaluates the RMS values of the three line-to-line voltages. If the lowest of the three line-to-line voltages falls below VFDet_LVFltThr or the highest of the three line-to-line voltages VFDet_HVFltThr for several consecutive control cycles (at 9KHz) the fault flag is set and the time since fault inception is measured. Several consecutive detection cycles are used to prevent triggering the fault by noise.

The fault flag is cleared as soon as all the three line-to-line voltages reenters and stays in the range of VFDet_LVRcyThr to VFDet_HVRcyThr for several consecutive control cycles.

Table 8 – Parameters for Voltage Fault Detection

Parameter	Description	Range	Default	Access Level
VFDet_LVFltThr	Low voltage fault threshold for the lowest of the three line-to-line voltages (Vpu)	0.5 to 0.99	0.9	2
VFDet_LVRcyThr	Low voltage fault recovery threshold for the lowest of the three line-to-line voltages. Must be greater than VFDet_LVFltThr (Vpu)	0.5 to 0.99	0.91	2
VFDet_HVFltThr	High voltage fault threshold for the highest of the three line-to-line voltages (Vpu)	1.01 to 1.5	1.1	2
VFDet_HVRcyThr	High voltage fault recovery threshold for the highest of the three line-to-line voltages. Must be less than VFDet_HVFltThr (Vpu)	1.01 to 1.5	1.09	2
VFDet_VNegFltThr	Threshold level of Negative sequence voltage to switch to the 2-Phase fault curve (Vpu)	0.01 to 0.5	0.033	2
VFDet_VNegRcyThr	Fault recovery threshold for negative sequence voltage (Must be less than VFDet_VNegFltThr) (Vpu)	0.01 to 0.5	0.03	2
FaultRecDelayTms	Blocking delay after start of a fault (ms).	0 to 10000	5000	3

9.2 Fault Ride-Through

Under fault conditions, the PQstorI will continue to ride through and (where enabled) deliver reactive current into the grid for as long as the fault condition exists. It is possible through the use of various ride through curves, to provide the means to stop delivering reactive current but continue to ride through the fault. As a minimum though, these curves must be set to meet the applicable grid code ride-through and support requirement. These are sometimes referred to as “must-remain-connected curves” in some grid codes.

An example is given in Figure 14 applicable for VDE 4110. It should be clarified here that these are not trip curves though if the fault conditions exceed these curves, it is allow to trip due to limitations of the inverter.

There are different parameters for:

– Low Voltage Ride-Through 3-phase

– Low Voltage Ride-Through, 2-phase

– High Voltage Ride Through

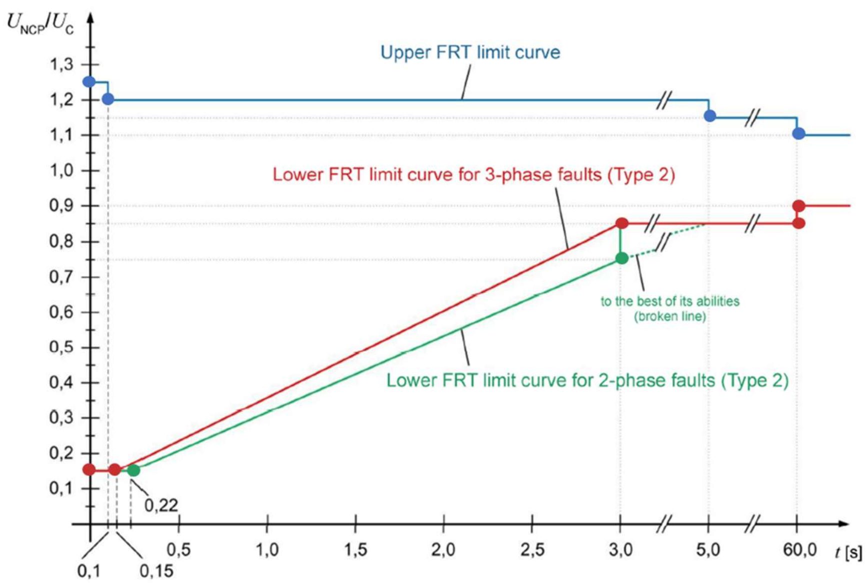


Figure 14 – Example of Fault Ride-Through limit curve

9.2.1 Low Voltage Ride-Through, 3-phase faults

The parameters for this curve are listed in Table 9. LVRT_ModEna also enables the 3-phase symmetric low voltage fault ride through. The curve is defined using point-arrays (See section 8.2.1 for an explanation of point-arrays). If two points differ in both the x and the T value the function interpolates, similar to that shown in Figure 14 for the red curve.

If level and duration of a fault extends beyond the curve a flag is set (which can be read via TV31_LvrtSt) but no other action is taken. This can thus be used by any external controller to perform additional actions.

Table 9 – Parameters for low voltage ride-through, symmetric fault

Parameter	Description	Range	Default	Access Level
LVRT_ModEna	Enables/ disables the function	0 or 1	0	4
VRT_RvrtTms	Timeout period (ms)	0 to 60000	5000	1
LVRT_3Ph_NumPts	Number of points in the array	0 to 15	5	2
LVRT_3Ph_SP0_x	Point 0, voltage value (Vpu)	0.0 to 100.0	0.9	2
LVRT_3Ph_SP0_T	Point 0, time value (s)	0.0 to 3600.0	60	2
[…]	[…]	[…]	[…]	
LVRT_3Ph_sP14_x	Point 14, voltage value (Vpu)	0.0 to 100.0		2
LVRT_3Ph_sP14_T	Point 14, time value (s)	0.0 to 3600.0	0	2

9.2.2 Low Voltage Ride-Through, 2-phase faults

The parameters for this curve are listed in If level and duration of a fault extends beyond the curve a flag is set (which can be read via TV31_LvrtSt) but no other action is taken. This can thus be used by any external controller to perform additional actions.

Table 9 which is enabled, as for the 3-phase curve, by the parameter LVRT_ModEna.

If two points differ in both the x and the T value the function interpolates, similar to that shown in Figure 14 for the green curve.

If level and duration of a fault extends beyond the curve a flag is set (which can be read via TV31_LvrtSt) but no other action is taken. This can thus be used by any external controller to per-form additional actions.

Table 10 – Parameters for low-voltage ride-through, asymmetric fault

Parameter	Description	Range	Default	Access Level
LVRT_2Ph_NumPts	Number of points in the array	1 to 15	6	2
LVRT_2Ph_sP0_x	Point 0, voltage value (Vpu)	0.0 to 100.0	0.033	2
LVRT_2Ph_sP0_T	Point 0, time value (s)	0.0 to 3600.0	60	2
[…]	[…]	[…]	[…]	
LVRT_2Ph_sP14_x	Point 14, voltage value (Vpu)	0.0 to 100.0	0	2
LVRT_2Ph_sP14_T	Point 14, time value (s)	0.0 to 3600.0	0	2

9.2.3 High Voltage Ride Through

The parameters for this curve are listed in Table 11. The interpretation of the point array is different from the standard interpretation insofar that is will not interpolate between two points. Therefore, only the upper right corner points of the curve need to be specified, similar to that shown in Figure 14 for the blue curve.

If level and duration of a fault extends beyond the curve a flag is set (which can be read via TV31_LvrtSt) but no other action is taken. This can thus be used by any external controller to per-form additional actions.

Table 11 – Parameters for high voltage ride through

Parameter	Description	Range	Default	Access Level
HVRT_ModEna	Enables/disables the function	0 or 1	0	4
HVRT_Max_Volt_Ratio	Max AC/DC voltage ratio in order to provide HVRT dynamic network support (Vpu)	0.5 to 1.0	0.735	1
HVRT_Volt_Ratio_Hyst	Level of hysteresis relating to the HVRT voltage ratio	0.0 to 0.1	0	1
HVRT_3ph_NumPts	Number of points in the array	1 to 15	4	2
HVRT_3ph_sP0_x	Point 0, voltage value (Vpu)	0.0 to 100.0	1.1	2
HVRT_3ph_sP0_T	Point 0, time value (s)	0.0 to 3600.0	60	2
[…]	[…]	[…]	[…]	
HVRT_3ph_sP14_x	Point 14, voltage value (Vpu)	0.0 to 100.0	0	2
HVRT_3ph_sP14_T	Point 14, time value (s)	0.0 to 3600.0	0	2

Under high voltage ride, constraints exist that are inherent to the design of the inverters. The first is linked to the actual rating of the inverter. The second is the level of charge on the batteries. Any battery voltage below 660Vdc will not be able to support 125% over-voltage for example. The curve shown in Figure 15 demonstrates this.

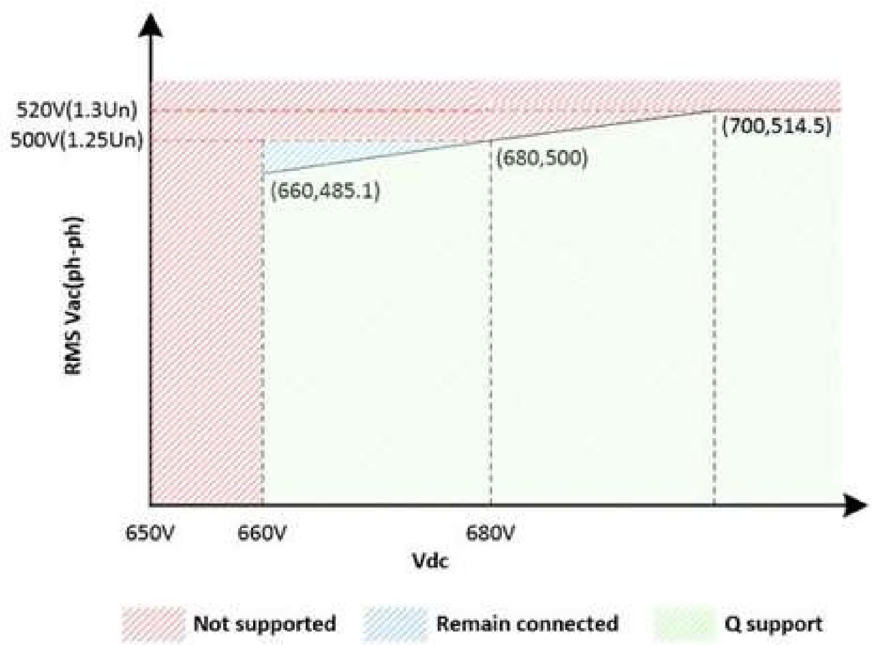


Figure 15 - High voltage ride through in relation to DC bus voltage at a base voltage of 400Vp-p

In the example of VDE Fault ride-through limit curve, it does not distinguish between the HVRT symmetrical fault and asymmetrical fault. Therefore, only the HVRT 3-phase curve is applicable. However, it is possible to have different curves for HVRT asymmetrical fault by using the parameters in Table 12.

Table 12 – Parameters for high voltage ride through

Parameter	Description	Range	Default	Access Level
HVRT_ModEna	Enables/disables the function	0 or 1	0	4
HVRT_2ph_NumPts	Number of points in the array	1 to 15	4	2
HVRT_2ph_sP0_x	Point 0, voltage value (Vpu)	0.0 to 100.0	1.1	2
HVRT_2ph_sP0_T	Point 0, time value (s)	0.0 to 3600.0	60	2
[…]	[…]	[…]	[…]	
HVRT_2ph_sP14_x	Point 14, voltage value (Vpu)	0.0 to 100.0	0	2
HVRT_2ph_sP14_T	Point 14, time value (s)	0.0 to 3600.0	0	2

9.3 Dynamic grid support

Dynamic grid support is achieved through the injection of reactive current.

Once the onset of a fault is detected by low/high voltage fault detection, the power generating units provide voltage support by adjusting (increasing or decreasing) the reactive current by an additional reactive current ΔIB.

This additional reactive current ΔiB is proportional to the voltage deviation Δu (ΔiB = k · Δu), where k is the amplification factor. It is defined by the straight line (2 ≤ k ≤ 6) shown in Figure 16. The additional reactive current in the positive-sequence system, ΔiB1, is proportional to the change of the positive-sequence voltage Δu1, whereas the additional reactive current in the negative-sequence system, ΔiB2, is proportional to the change of the negative-sequence voltage Δu2.

The amplification factor k is adjustable in steps of 0,5 between 2 and 6.

This function is implemented using TV31, see section 9.3.1.

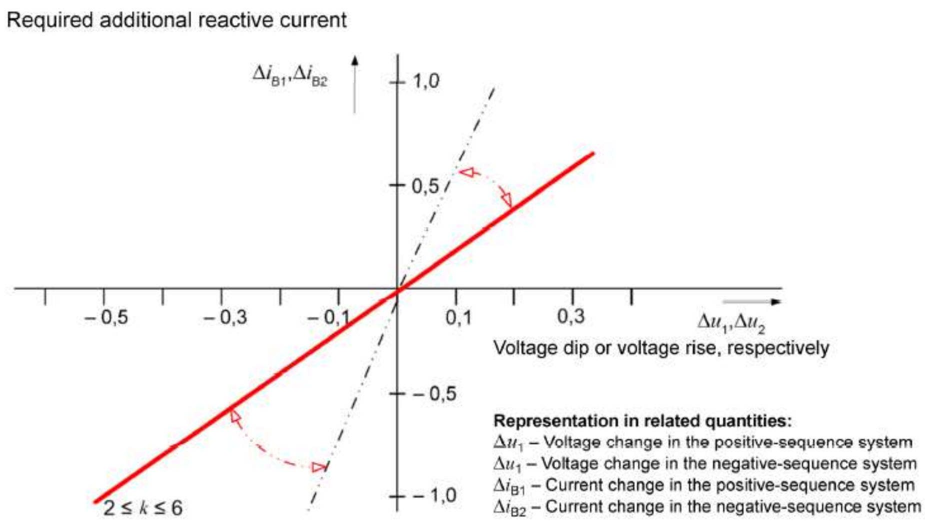


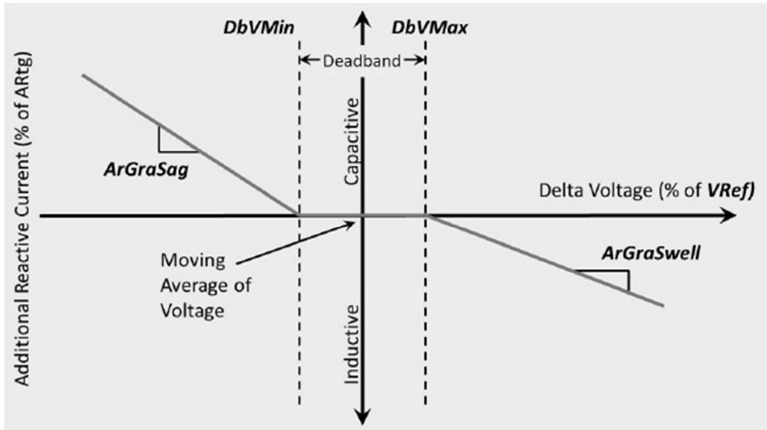
Figure 16 – Principle of the voltage support in the event of a network fault

9.3.1 Dynamic reactive current support mode TV31

The purpose of TV31 is to support the grid with reactive current during a fault resulting in abnormally low or high voltages. The basic curve is shown in Figure 17. The function is controlled by the parameters in Table 13.

No action is performed as long as TV31_ModEna is zero. When TV31_ModEna is non-zero the function will check if a fault is present and measure the time since fault inception. If a fault is active the parameter TV31_DelTmms controls when reactive current will be injected. The function continuously updates the moving average of both the positive and negative sequence voltage amplitudes. While a fault is active the averages are frozen and the delta between the current and frozen voltage amplitudes are used as input to the curve in Figure 17. The result are reactive currents to be injected into both the positive and negative sequence system.

If TV31_ArGraMod equals 2 and the voltage reenters the dead band the reactive current still follows the gradients TV31_ArGraSag and TV31_ArGraSwell until the hold time TV31_HoldTmms is up.



IEC 437/13

Figure 17 – Principle of TV31

9.3.2 Limited and Restricted dynamic network stability

The requirements of both Limited and Restricted dynamic network stability as defined under VDE-AR-N 4105 and 4110 respectively, are satisfied using the parameter TV31_RLDNS.

When TV31_RLDNS is set to 1 (for 4105), no apparent current is injected when the lowest RMS voltage is less than 80% of VRef. Also the same will occur when the highest RMS voltage exceeds 115% of VRef.

When TV31_RLDNS is set to 2 (for 4110), no apparent current is injected when the lowest RMS voltage is less than 70% of VRef.

Two additional options have been added in order to enable customer set Q requirements necessary for their plant, to still be satisfied. These have the same limits as in modes 1 and 2 but where pre-fault set Q is not suppressed during the fault.

Under TV31 described within IEC 61850-90-7 [3], there is a similar function described as the blocking zone where no current is injected if the block zone is entered (see Figure 18).

The blocking zone will be entered when at the time since fault inception, the timer TV31_BlkZnTmms is exceeded, and the RMS voltage is less than TV31_BlkZnV. The block zone is exited only when the voltage rises above TV31_BlkZnV + TV31_HysBlkZnV.

No current is injected until the time since fault inceptions is greater than TV31_DelTmms.

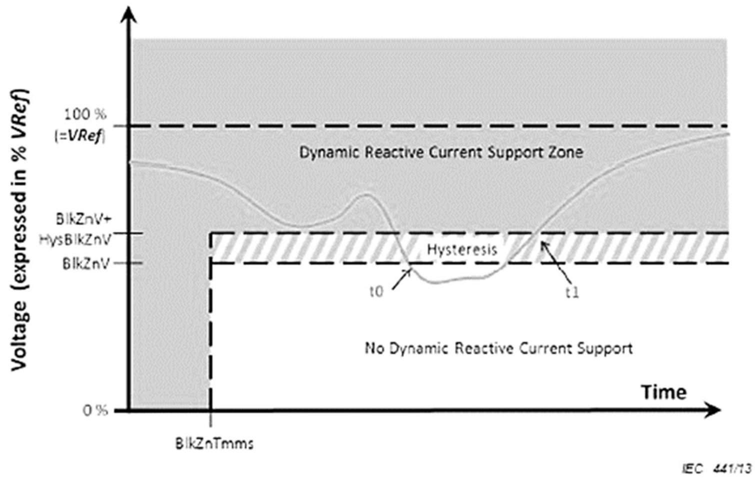


Figure 18 – The various parameters used to define the blocking zone

Table 13 – TV31 Parameters. At a minimum the ones red has to be defined

Parameter	Description	Range	Default	Access Level
TV31_ModEna	Activation of dynamic reactive current support function	0 or 1	0	4
TV31_RLDNS	Restricted limited dynamic network stability enable/disable 0 = Disabled 1 = Limited dynamic network response (LDNS) enabled 2 = Restricted dynamic network response (RDNS) enabled 3 = LDNS enabled but customer set Q not cancelled 4 = RDNS enabled but customer set Q not cancelled	0, 1, 2, 3 or 4	0	4
TV31_ArGraMod	Mode of reactive current characteristic: selects between that edges, and where the gradients trend toward zero at the center 0 = Disabled 1 = Gradients trend toward zero at the dead band 2 = Gradient trend toward zero at the center	0, 1 or 2	2	2
TV31_ArGraSag	Gradient for reactive current during a voltage sag (0 gradient implies no reactive current feed-in)	0.0 to 10.0	2	2
TV31_ArGraSwell	Gradient for reactive current during a voltage swell (0 gradient implies no reactive current feed-in)	0.0 to 10.0	2	2
TV31_FilTms	Filter time window for calculating moving average voltage (s)	0 to 120	60	1
TV31_HoldTmms	Hold time (ms)	0 to 60	10	1
TV31_DelTmms	Delay time prior to current injection (ms)	0 to 100	15	1
TV31_DbVMin	Lower limit, voltage dead band (Vpu)	0.0 to 1.0	0	2
TV31_DbVMax	Upper limit, voltage dead band (Vpu)	0.0 to 1.0	0	2
TV31_BlkZnTmms	Block zone time (ms)	0 to 10000	5000	2
TV31_BlkZnV	Block zone voltage (V)	0.0 to 690.0	0	2
TV31_HysBlkZnV	Hysteresis voltage (V)	0.0 to 100.0	0	2
TV31_Priority	Determines the priority of pre-fault priority for Positive and negative sequence currents during a fault.	0 or 1	0	1

9.4 Abrupt Voltage Response function

The abrupt voltage response function is used in conjunction with the TV31 dynamic support function providing the ability of the inverter to respond to sudden changes in voltage (over a tolerance band typically of +/-5%). An example of this is shown in Figure 19.

In order to identify an abrupt voltage event, the function uses a 50 cycle pre-fault voltage (as op-posed to the 1min moving average for TV31 with a tolerance band of +/-10%). This means that the tolerance band is moving up and down within the normal voltage range.

With reference to the example shown in Figure 19, such an event occurs at t1 where the measured voltage exceeds the abrupt voltage tolerance band. The end of the fault in this case is t2.

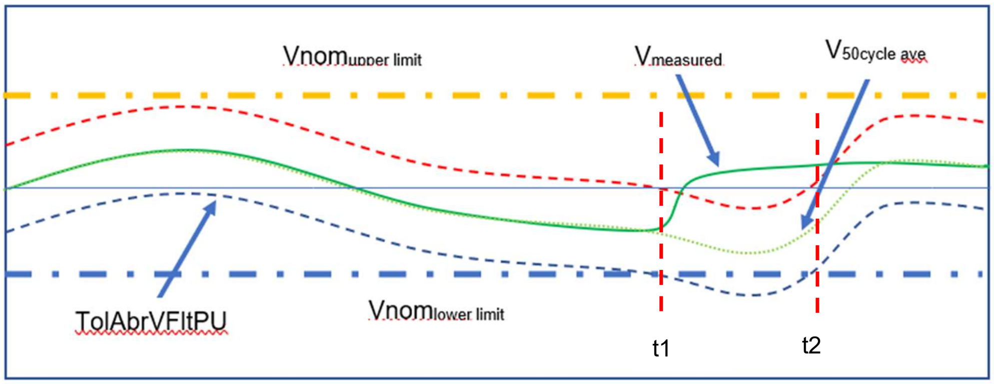


Figure 19 – Example abrupt voltage change from VDE-AR-N 4110

The additional parameters specific to this function are shown in Table 14.

Table 14 – Abrupt Voltage response

Parameter	Description	Range	Default	Access Level
Abrupt_ModEna	Abrupt voltage response mode enabled	0 or 1	0	4
TolAbrVFltPU	Tolerance levels for the Abrupt voltage response (Vpu)	0.0 to 0.15	0.05	3
TimeAbrVFltRcvy	Time during which the abrupt voltage response will operate (ms)	0 to 10000	5000	3

10 Protections

The PQstorI includes the functionality for the various protection requirements under VDE-AR-N 4105/4110 but as of the time of this publication, these have not been enabled as the PQstorI does not have the means to make remote 3Ph+N measurements of voltage. That is, it is not able to measure the status of the voltage at the grid side of the main disconnection switch to enable reconnection. These functions are thus presently being satisfied by the centralized NS-protection relay. Nevertheless, their implementation and setup are described below.

Protections are defined in terms of must-disconnect curves. An example is given in Figure 20. The curve is defined using point-arrays. Notice that for these functions the segments between the points are not interpolated. Therefore, only every other point needs to be defined. For the curves controlling the lower limit only the upper left corner points are defined. For the curves controlling the upper limit only the lower left corner points are defined.

It should also be noted that there is a conflict between the FRT curves and the Must disconnect. This is due to the fact that these would typically be based on two different measurement locations. One being at the connection point of the device while for any centralized NS-Protection relay, the voltage measurement would be upstream of the Main disconnector and closer to the PCC (point of common coupling).

Note: The order of the points in the point-arrays are of importance. The points must be arranged in the order from less severe to most severe violations. In other words, for the upper limit the points must be arrange in the order of ascening x-values. The lower limit the points must be arranged in the order of descending x-values.

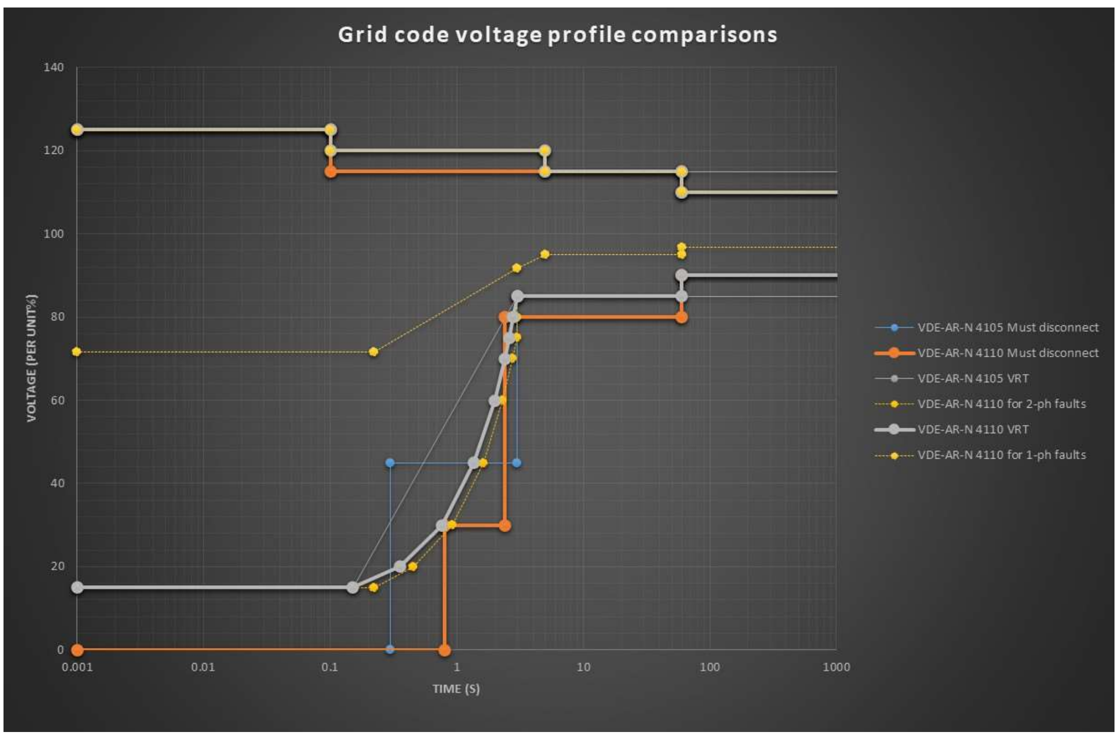


Figure 20 – Example of must-disconnect curves

10.1 AC Over Voltage

The parameters for this function are listed in Table 15.

Table 15 – Parameters for AC over-voltage protection

Parameter	Description	Range	Default	Access Level
HVRTD_ModEna	Enables/disables the function	0 or 1	0	4
HVRTD_NumPts	Number of points in the array	1 to 15	3	2
HVRTD_sP0_x	Point 0, voltage value (Vpu)	0.0 to 100.0	1.15	2
HVRTD_sP0_T	Point 0, time value (s)	0.0 to 3600.0	60	2
[…]	[…]	[…]	[…]	
HVRTD_sP14_x	Point 14, voltage value (Vpu)	0.0 to 100.0	0	2
HVRTD_sP14_T	Point 14, time value (s)	0.0 to 3600.0	0	2

10.2 AC Under Voltage

The parameters for this function are listed in Table 16.

Table 16 – Parameters for AC under-voltage protection

Parameter	Description	Range	Default	Access Level
LVRTD_ModEna	Enables/disables the function	0 or 1	0	4
LVRTD_NumPts	Number of points in the array	1 to 15	3	2
LVRTD_sP0_x	Point 0, voltage value (Vpu)	0.0 to 100.0	0.9	2
LVRTD_sP0_T	Point 0, time value (s)	0.0 to 3600.0	60	2
[…]	[…]	[…]	[…]	
LVRTD_sP14_x	Point 14, voltage value (Vpu)	0.0 to 100.0	0	2
LVRTD_sP14_T	Point 14, time value (s)	0.0 to 3600.0	0	2

10.3 Over Frequency

The parameters for this function are listed in Table 17.

Table 17 – Parameters for AC over-frequency protection

Parameter	Description	Range	Default	Access Level
HFRTD_ModEna	Enables/disables the function	0 or 1	0	4
HFRTD_NumPts	Number of points in the array	1 to 15	3	2
HFRTD_sP0_x	Point 0, Frequency value (Hz)	0.0 to 100.0	51	2
HFRTD_sP0_T	Point 0, time value (s)	0.0 to 3600.0	1800	2
[…]	[…]	[…]	[…]	
HFRTD_sP14_x	Point 14, Frequency value (Hz)	0.0 to 100.0	0	2
HFRTD_sP14_T	Point 14, time value (s)	0.0 to 3600.0	0	2

10.4 Under Frequency

The parameters for this function are listed in Table 18.

Table 18 – Parameters for AC under-frequency protection

Parameter	Description	Range	Default	Access Level
LFRTD_ModEna	Enables/disables the function	0 or 1	0	4
LFRTD_NumPts	Number of points in the array	1 to 15	2	2
LFRTD_sP0_x	Point 0, Frequency value (Hz)	0.0 to 100.0	49	2
LFRTD_sP0_T	Point 0, time value (s)	0.0 to 3600.0	1800	2
[…]	[…]	[…]	[…]	
LFRTD_sP14_x	Point 14, Frequency value (Hz)	0.0 to 100.0	0	2
LFRTD_sP14_T	Point 14, time value (s)	0.0 to 3600.0	0	2

10.5 Anti-Islanding

The objective of anti-Islanding protection is to ensure the prevention of any unintentional islanding. Unintentional islanding comes with severe adverse consequences to maintenance personnel as well as equipment connected to the grid.

The method used for the PQstorI module is active frequency drift with positive feedback. In the case of a grid disconnection, the supply frequency is shifted by the control algorithm towards the extreme upper or lower frequency limits depending on the load resonance frequency. When shift in frequency reaches set frequency limits it disconnects the PQstorI from the grid. This process (from the opening of the main grid connection breaker/contactor to stopping of the PQstorI) is accomplished within the 2s maximum limit defined by the grid codes.

The set frequency limits are defined by the frequency protection parameters under LFRTD and HFRTD as per Table 16 and Table 17 respectively. Whenever grid frequency shifts below the lowest sLFRTD_sP_x or above highest sHFRTD_sP_x frequency limits, the PQstorI disconnects within as-sociated time of sLFRTD_sP_T and sHFRTD_sP_T respectively.

Anti-islanding is enabled/disabled by flag iAI_ModEna as below:

Table 19 – Active Anti-islanding parameter table

Parameter	Description	Range	Default	Access Level
iAI_ModEna	Enables/ disables Anti Islanding	0 or 1	1	4

10.6 Reconnection

At the time of the publication of this document, the PQstorI did not include any grid code reconnection functionality. This will be satisfied using a centralized NS-protection relay. As such all the voltage and frequency protection requirements will also be satisfied by this device.

11 Additional Grid Code Functions

The above-described functions are based on the functionality and data models described in [3]. This section describes some of the additional grid code functions that have been created using the IEC models as a guide. In many cases they provide very similar responses to that created to meet the VDE grid code requirements but using different methods in achieving this. In the case of VV11 and VV12, they actually form part of the functions in achieve VDE mode 1 and 2 as described above.

11.1 INV3: adjust power factor

Fixed power factor is managed through issuing a power factor value and corresponding excitation. The function is controlled by parameters listed in Table 20.

Table 20 – INV3 Parameters

Parameter	Description	Range	Default	Access Level
INV3_OpModConPF	Enable the power factor function	0 or 1	0	4
INV3_OutPFSet	Setpoint for maintaining fixed power factor	-1.0 to -0.6, 0.6 to 1.0	0.93	4
INV3_PFsign	Power Factor Sign convention (see Appendix B: Power factor sign conventions) 1 = IEC 2 = IEEE	1 or 2	2	2
INV3_PFExt	Power Factor excitation 0 = Overexcited (capacitive), 1 = Underexcited (inductive)	0 or 1	1	4

No action is performed while INV3_OpModConPF or INV3_OutPFSet equals zero. When both parameters are on zero the power factor INV3_OutPFSet is maintained.

If the parameter INV3_PFsign equals 1, the sign of INV3_OutPFSet is ignored and INV3_PFExt de-fines whether the reactive power output is under or overexcited.

If the parameter INV3_PFsign equals 2, the parameter INV3_PFExt is ignored and the sign of INV3_OutPFSet together with the sign of the active power setpoint (fSet_P) define, if the reactive power output is under or overexcited.

11.2 Frequency-watt mode FW21

This frequency-watt mode is one of two methods to address the issue of rising frequency, often a sign of too much power generation to the grid (and vice versa when energy storage exists). The basic principle is shown in Figure 21. The function is controlled by the parameters in Table 21. It is often used for emergency instability situations.

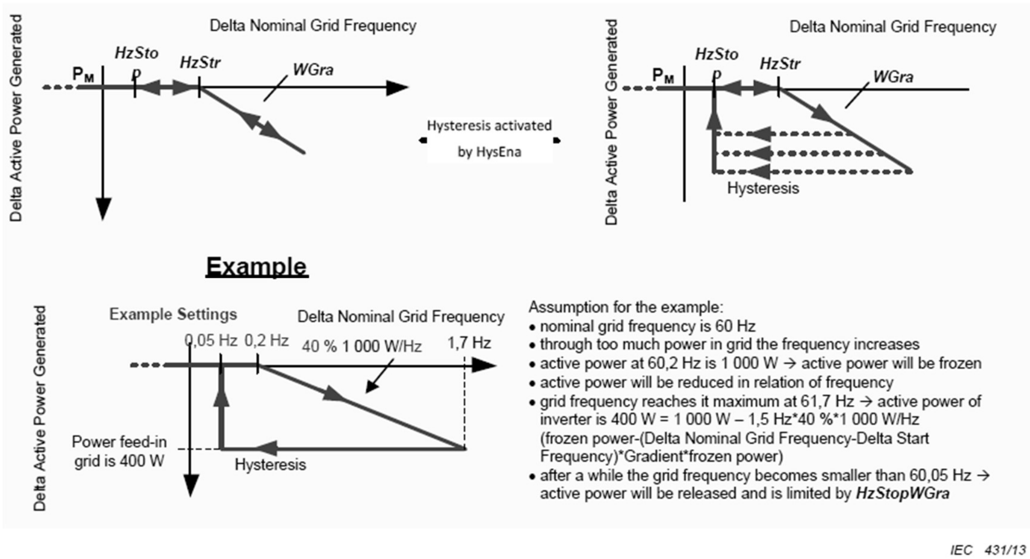


Figure 21 – Principle of FW21

Table 21 – FW21 Parameters

Parameter	Description	Range	Default	Access Level
FW21_WCtlHzEna	Activation of the Active Power Reduction by Frequency function	0 or 1	0	4
FW21_HysEna	Hysteresis enable 0 = No hysteresis 1 = Use of hysteresis	0 or 1	1	4
FW21_WGra	Active power gradient in percent of frozen active power value per Hz (puW/Hz).	0.0 to 1.0	1	2
FW21_HzStop	Delta frequency between stop frequency and nominal grid frequency (Hz).	0.0 to 5.0	0.1	2
FW21_HzStr	Delta frequency between start frequency and nominal grid frequency (Hz).	0.0 to 5.0	0.2	2
FW21_HzStopWGra	The maximum time-based rate of change at which power output returns to normal after having been capped by an over frequency event (WMax/min).	0.0 to 1.0	0.1	1
FW21_SnptW	Snapshot of power: 0 Off, the snapshot is not active (read only)	0 or 1	0	2

No action is performed as long as FW21_WCtlHzEna zero. When FW21_WCtlHzEna is non-zero the function feeds the current frequency value into the curve shown in Figure 21. When the frequency is greater than the nominal frequency plus FW21_HzStr a snapshot of the active power user-setpoint (fSet_P) is taken and stored in FW21_Pm. Furthermore, the active power output is reduced to the percentage of FW21_Pm defined by the curve.

If FW21_HysEna equals zero, frequency variations will cause the active power output to move up and down the curve defined by FW21_WGra and FW21_HzStr. If FW21_HysEna is non-zero a de-crease of the frequency towards the nominal will not change the active power output until the frequency reaches fFW21_HzStop.

If FW21_HzStopWGra equals zero upon re-entering the zone defined by the nominal frequency and FW21_HzStop, the active power output will snap back to FW21_Pm.

If FW21_HzStopWGra is non-zero upon re-entering the zone defined by the nominal frequency and FW21_HzStop, the active power output will return to Set_P with a rate of change defined by FW21_HzStopWGra.

11.3 Volt-Var Modes VV11 and VV12

Volt-var modes define the injection of reactive power in response to voltage variation. An example is shown in Figure 22. The Volt-Var dependency is defined by a series of points (i.e. the point array). The parameters have the same meaning as the ones listed in Table 6, however their names start with “VV11” and “VV12”. The evaluation of the point array follows the same rules a described for FW22.

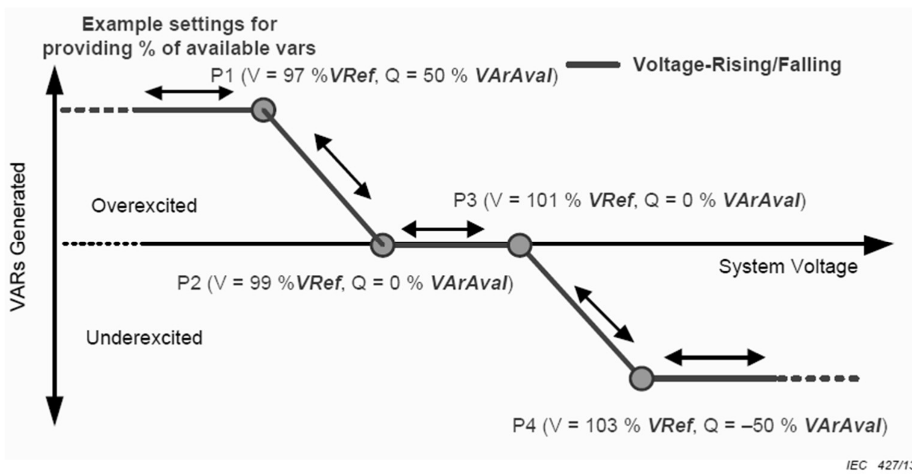


Figure 22 - Principle of Volt-Var mode

For VV11 the parameter VV11_DeptRef should be set to 3, i.e the function produces VArs as per-cent of maximum available vars (VArAval). Other values of DeptRef produce a different behavior.

For VV12 the parameter VV12_DeptRef should be set to 4 the function produces VArs as percent of maximum watts (WMax). However, other values of DeptRef can also be chosen that will produce the corresponding behavior.

When either VV11 or VV12 are enabled using VV11_ModEna or VV12_ModEna via the point array, the function will result in the change of the Dependent reference (DeptRef) as the voltage changes following the curve created through the point array.

Both VV11 and VV12 operate in the same way thus provide the ability to choose between two different curves when they are individually enabled. It is not possible for both to operate at the same time.

11.4 Watt-power factor mode WP41: feed-in power controls power factor

This function is similar to the VDE mode 4 Q(P) function described in section 7.5 above but where the defined curve is representing the change in Power Factor (rather than Q) against Power and uses fixed parameters instead of a point array.

This watt-power factor mode is shown in Figure 23 where the amount of active power provided at the ECP can be set to gradually modify the power factor. When WP41_PFCtlWEna equals 1, reactive power is output corresponding to the power factor retrieved from the curve in Figure 23 using the parameters listed in Table 22.

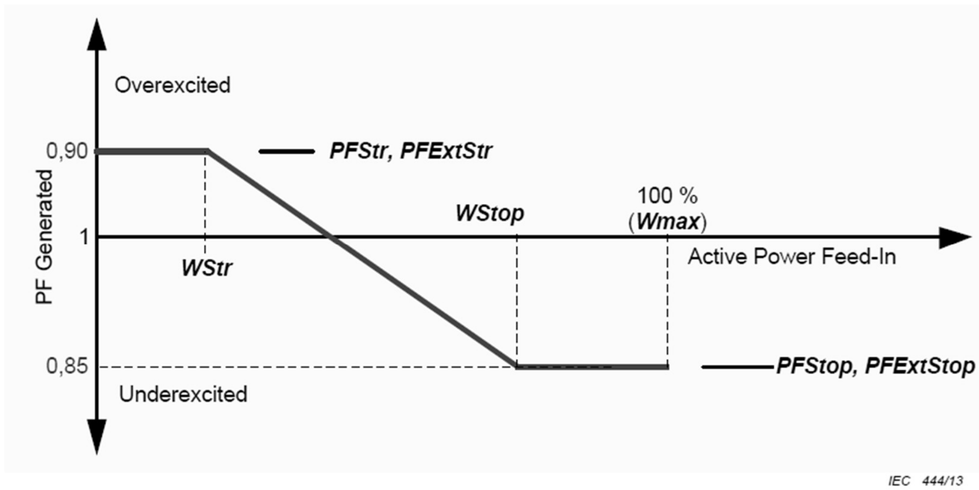


Figure 23 – Principle of WP41

Table 22 – WP41 Parameters

Parameter	Description	Range	Default	Access Level
WP41_PFCtlWEna	Activation of WP41	0 or 1	0	4
WP41_WStr	Power of start point (Ppu)	-1.0 to 1.0	0.2	3
WP41_WStop	Power of stop point (Ppu)	-1.0 to 1.0	0.4	3
WP41_PFStr	Power factor of start point	-1.0 to -0.6, 0.6 to 1.0	0.9	3
WP41_PFStop	Power factor of stop point	-1.0 to -0.6, 0.6 to 1.0	0.85	3
WP41_PFExtStr	Excitation of start point 0 = overexcited, 1 = Underexcited	0 or 1	0	3
WP41_PFExtStop	Excitation of stop point 0 = overexcited, 1 = Underexcited	0 or 1	1	3

11.5 Voltage-watt mode VW51 and VW52

Similar to the frequency-watt mode FW22 a voltage-watt management can be used for smoothing voltage deviations. Voltage-watt management modes VW51 and VW52 are also based on point-arrays similar to FW22. An example is shown in Figure 24.

For both modes parameter DeptRef should be set to 5, i.e the function produces Watts as percent of maximum watts (WMax). Other values of DeptRef produce a different behavior.

VW51 defines the allowable level of generation (discharge) depending on voltage, whereas VW52 defines the allowable level of charge depending on voltage. That is to say that as the voltage in-creases the available power for discharge will be constrained by VW51 while as the voltage de-creases, the power that can be absorbed (for charging) becomes constrained.

VW51 shall be defined with point arrays having positive y-values only while VW52 shall be defined with point arrays having negative y-values only.

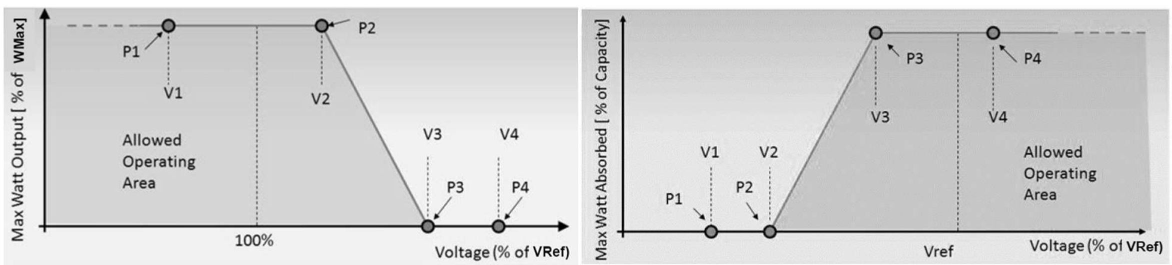


Figure 24 – VW51/VW52 Principle

11.6 Rate of Change of Frequency RoCoF

The RoCoF function is one of the methods often used to detect possible loss of mains (islanding). It is regarded as a passive anti-islanding function since it does not actively provide energy into the grid in order to detect a response. It will only be enabled when required by a particular grid code.

It works by detecting an adjustable number of cycles (using voltage zero crossing) in order to calculate the rate of change of frequency. If this exceeds a set limit for particular delay time, it will cause the grid disconnector to open.

Table 23 shows the available parameters. An error time parameter exists to delay the evaluation of the switch-on condition if auto reconnection is enabled (typically zero though the default here is 0.5s).

Table 23 – RoCoF Parameters

Parameter	Description	Range	Default	Access Level
RoCoF_ModEna	Enable rate of change of frequency protection method	0 or 1	0	4
RoCoF_trip_Freq_rate	Threshold rate of change of frequency (Hz/s)	0.1 to 5.0	2.5	1
RoCoF_trip_delay_time	Delay time from detection to tripping (s)	0.0 to 600.0	0.08	1
RoCoF_Number_of_cycles	Adjustable number of cycles in order to calculate the rate of change of frequency using voltage zero crossings	4 to 60	5	1
RoCoF_error_time	Switch-on conditions evaluated as part of auto re-connection only after the set error time (s)	0.5 to 600.0	0	1

11.7 Additional Grid Code Parameter

11.7.1 GCFuncActive

The PQstorI includes the parameter "GCFuncActive" which provides indication of the various grid code functions that are active at any time. This provides a decimal value that can be converted into a binary value to indicate what function is active at a particular time. It is possible to monitor this continuously in order to provide information to the end user. The Table 24 provides the bit map for de-coding the GCFuncActive paremeter.

Example: During a Low voltage ride through event, the value read from this parameter indicates 1538. This translates to those functions indicated in green in the table.

Recorded value (Decimal)	1538
Calculated value (Binary)	0000011000000010

Table 24 – Bit Map for Grid code function active parameter

Bit Number	Grid Code Function Active
0	Reserved
1	AbruptVolt
2	FW21
3	FW22
4	HVRT
5	INV3
6	INV4
7	LVRT
8	ReconnRmpUp
9	TV31
10	VDE_Ctrl
11	VV11
12	VV12
13	VW51
14	VW52
15	WP41

11.7.2 PExportLim and PImportLim

Two Power limitation input parameters have been added in order that the energy management system (EMS) can better limit the import or export of the inverter due to limitations existing within the system. These are not grid code parameters and so their use must be used solely for the purpose of ensuring the operation of the system within its operational limits and with agreement of the grid operator.

One example would be during a LOW frequency event, there will be an automatic response from the inverter to export power into the grid. This would only be possible if the state of charge (SOC) of the system is such that sufficient energy exists. If the SOC is too low, then the EMS will use the PExportLim parameter to limit the amount of power delivered to the grid. Likewise during a HIGH frequency event, the automatic response would be to import power from the grid which would only be possible if the SOC is low. If the SOC is high, then PEImportLim will limit the further import of power into the Energy storage means.

Table 25 – RoCoF Parameters

Parameter	Description	Range	Default	Access Level
PExportLim	Export Limitation input from EMS (Ppu)	0.0 to 1.0	1	4
PImportLim	Import Limitation input from EMS (Ppu)	0.0 to 1.0	1	4

11.7.3 GCProfileID

The GCProfileID provides a unique identifier of the grid code profile that exists on the PQstorI. This value is required to be manually entered during the creation/modification of a profile. Hitachi Energy keeps a record of these IDs of all those profiles created by Hitachi. Any custom profiles created would thus require their own records to be kept.

Table 26 – RoCoF Parameters

Parameter	Description	Range	Default	Access Level
GCProfileID	Unique identifier of the Grid Code Profile	N/A	N/A	3

12 Appendix A: Direction definition of P and Q

For the VDE referenced drawings in this document the currents and voltages are taken as positive in the direction of the arrow (passive sign convention system). This is opposite to that used for the PQstorI where +P is generating and +Q is supporting the grid during low voltages.

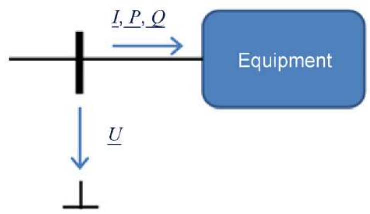


Figure B.10 – Positive direction of voltages and currents. Equipment includes, e.g., a demand facility, a power generating plant, a power generating unit or a FACTS element.

Figure 25 – Convention used in VDE references

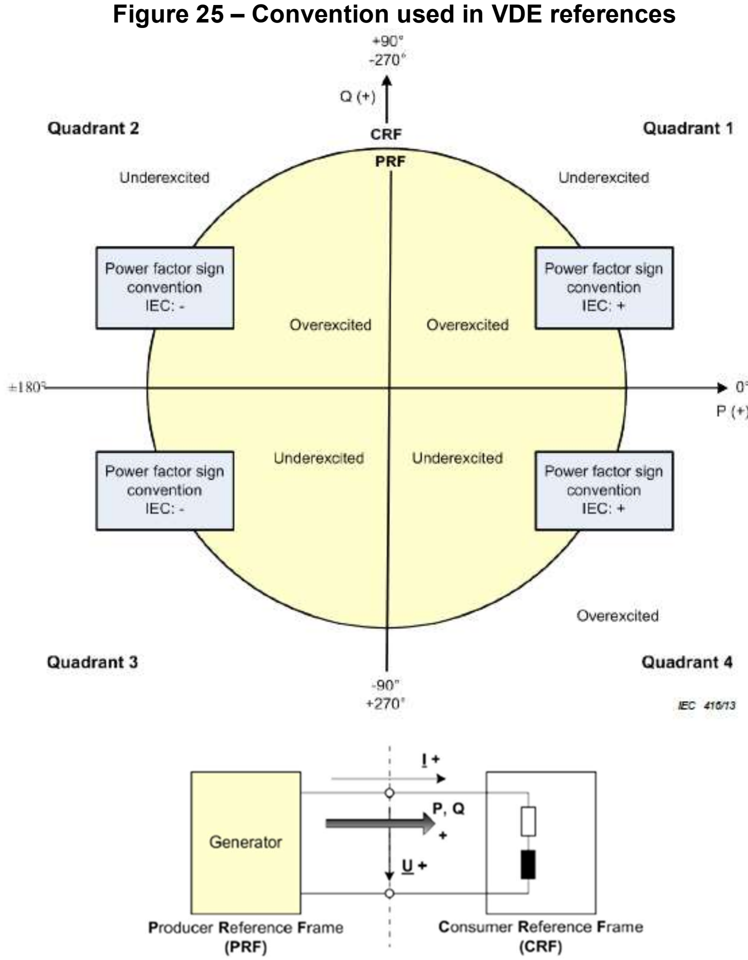


Figure 26 - Producer reference frame (ref IEC 61850-90-7)

13 Appendix B: Power factor sign conventions

The Power Factor sign can be positive or negative and both IEC and IEEE define these differently.

13.1 IEC

For IEC the PF sign correlates with the direction of real power (kW) flow.

– In quadrant 1 and 4 of Figure 26: Positive real power (+kW), the PF sign is positive (+).

– In quadrant 2 and 3 of Figure 26: Negative real power (-kW), the PF sign is negative (-).

13.2 IEEE

For IEEE the PF sign is correlates with the PF lead/lag convention. In other words, the effective load type (inductive or capacitive):

– For a capacitive load (PF leading, quadrant 2 and 4), the PF sign is positive (+).

– For an inductive load (PF lagging, quadrant 1 and 3), the PF sign is negative (-).

14 Appendix C – Grid Code Profile Manager

For details on working with the Profile management tool refer to the document PQstorI grid code profile management 2.00 user manual [4].

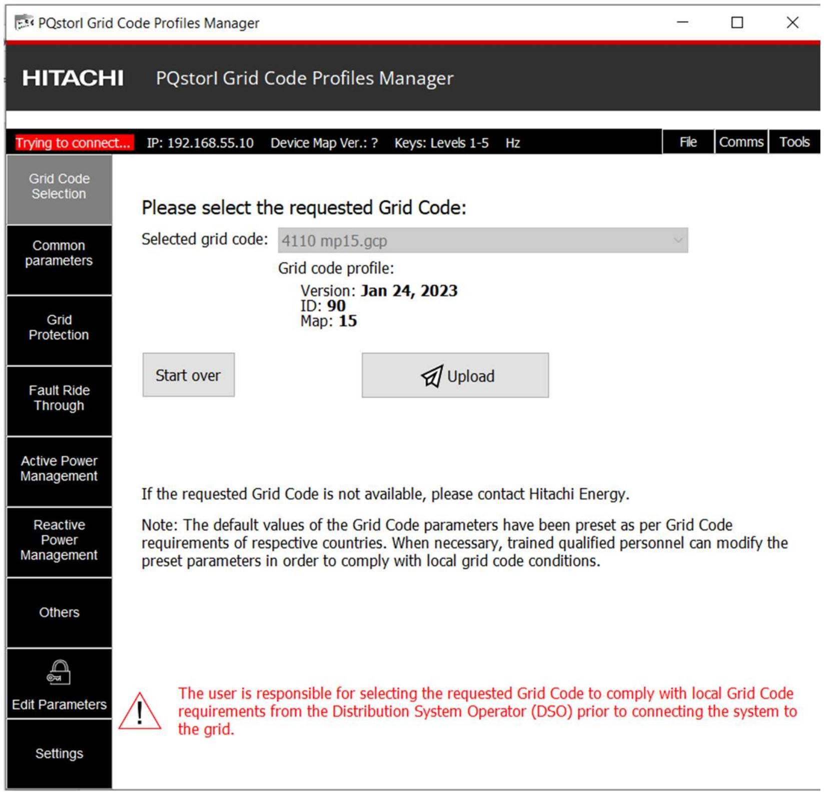


Figure 27 -Screenshot of Profile manager table

15 Appendix D – BESS representative system

The schematic shown in Figure 28 presents the various components that make up a battery energy storage system (BESS) that incorporates multiple PQstorI modules plus the various components necessary in order to connect to the grid.

All telecontrol signals must pass via the Energy management system (EMS) using the predefined parameters and the appropriate private key (see section 6). This ensures the minimum level of cyber security as well as safety of the grid.

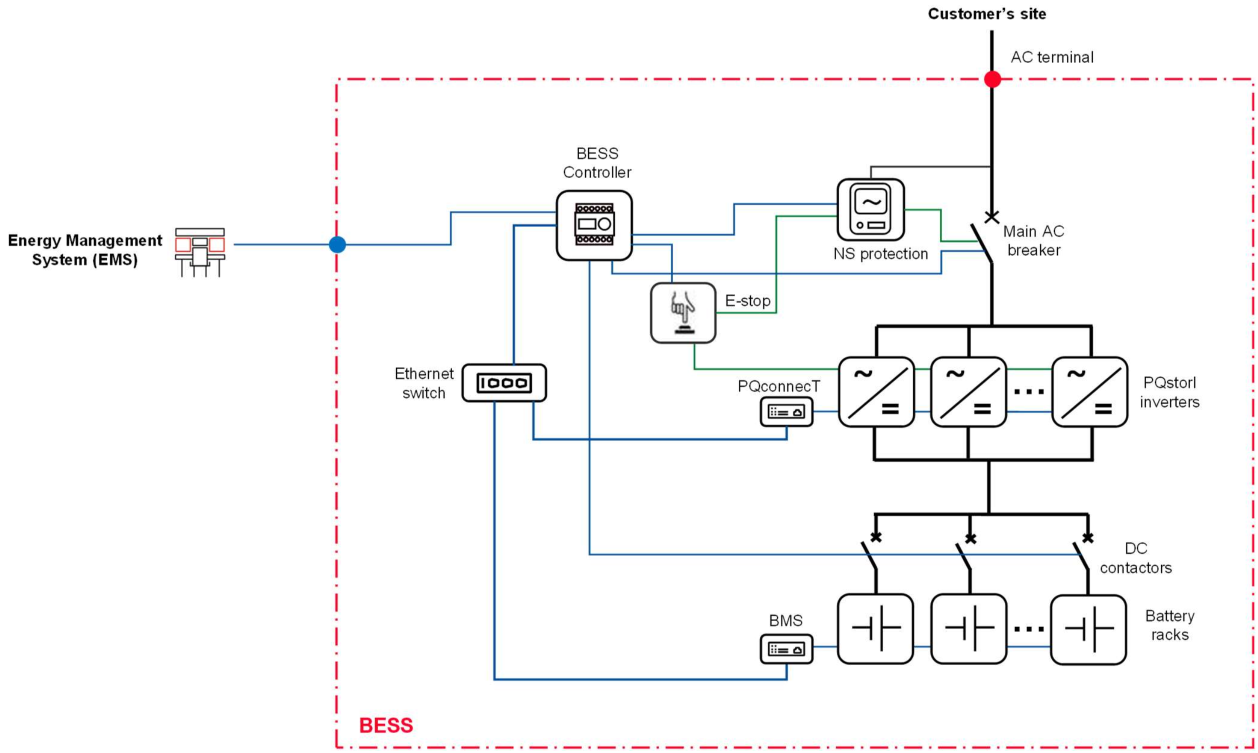


Figure 28 – Representation of a Battery Energy Storage System incorporating multiple PQstorI modules

16 Appendix E – PQ capability curve table of data

The table below shows a partial capture of the full PQ capability measurement data. The full data file can be provided as a separate datafile as required.

P@V=0.85 (pu)	Q@V=0.85 (pu)	P@V=0.90 (pu)	Q@V=0.90 (pu)	P@V=0.95 (pu)	Q@V=0.95 (pu)	P@V=1.0 (pu)	Q@V=1.0 (pu)	P@V=1.05 (pu)	Q@V=1.05 (pu)	P@V=1.1 (pu)	Q@V=1.1 (pu)	P@V=1.15 (pu)	Q@V=1.15 (pu)
0.865	0.015	0.912	0.035	0.964	0.017	1.002	0.019	1.002	0.021	1.005	0.02	1.005	0.037
0.86	0.038	0.917	0.027	0.965	0.017	1.002	0.019	1.002	0.021	1	0.025	1.006	0.037
0.859	0.037	0.917	0.028	0.963	0.017	1.002	0.019	1.002	0.021	1	0.025	1.006	0.037
0.86	0.038	0.917	0.027	0.964	0.017	0.985	0.2	1.002	0.021	0.999	0.025	1.005	0.037
0.859	0.037	0.916	0.027	0.963	0.017	0.985	0.2	0.986	0.202	0.983	0.204	0.986	0.222
0.86	0.037	0.916	0.027	0.964	0.028	0.969	0.274	0.985	0.202	0.983	0.204	0.983	0.222
0.859	0.036	0.916	0.028	0.964	0.046	0.969	0.274	0.969	0.276	0.967	0.278	0.965	0.296
0.859	0.035	0.917	0.027	0.956	0.092	0.952	0.33	0.969	0.276	0.966	0.278	0.966	0.296
0.859	0.034	0.917	0.027	0.947	0.197	0.952	0.33	0.952	0.332	0.95	0.333	0.949	0.352
0.859	0.033	0.917	0.028	0.94	0.222	0.936	0.377	0.952	0.332	0.95	0.333	0.948	0.352
0.858	0.032	0.916	0.027	0.931	0.269	0.936	0.377	0.936	0.379	0.934	0.38	0.931	0.398
0.859	0.03	0.917	0.027	0.925	0.288	0.919	0.417	0.936	0.379	0.934	0.379	0.931	0.398
0.858	0.03	0.916	0.028	0.915	0.323	0.919	0.417	0.919	0.419	0.917	0.419	0.914	0.438
0.858	0.028	0.917	0.027	0.908	0.339	0.902	0.452	0.919	0.419	0.917	0.419	0.914	0.438
0.858	0.027	0.916	0.027	0.899	0.368	0.902	0.452	0.902	0.454	0.901	0.454	0.896	0.471
0.857	0.026	0.901	0.181	0.892	0.381	0.886	0.481	0.902	0.454	0.901	0.454	0.896	0.472
0.858	0.024	0.902	0.181	0.881	0.407	0.886	0.481	0.886	0.483	0.884	0.483	0.879	0.497
0.857	0.024	0.886	0.252	0.875	0.418	0.869	0.526	0.886	0.483	0.885	0.483	0.879	0.496
0.858	0.022	0.886	0.252	0.866	0.442	0.869	0.526	0.869	0.493	0.868	0.528	0.862	0.496
0.859	0.021	0.868	0.313	0.859	0.45	0.852	0.549	0.869	0.494	0.868	0.493	0.862	0.496
0.857	0.023	0.867	0.313	0.849	0.468	0.853	0.549	0.853	0.551	0.852	0.551	0.845	0.568
0.844	0.17	0.851	0.358	0.842	0.469	0.836	0.574	0.853	0.551	0.852	0.551	0.845	0.568
0.843	0.17	0.851	0.357	0.833	0.511	0.836	0.574	0.836	0.576	0.835	0.575	0.828	0.593
0.829	0.238	0.835	0.396	0.826	0.522	0.819	0.598	0.836	0.576	0.835	0.575	0.828	0.593
0.829	0.237	0.835	0.397	0.816	0.536	0.819	0.598	0.819	0.6	0.819	0.599	0.811	0.617
0.812	0.29	0.818	0.43	0.809	0.546	0.803	0.62	0.819	0.6	0.819	0.599	0.811	0.617
0.813	0.29	0.818	0.431	0.799	0.56	0.802	0.62	0.802	0.622	0.803	0.621	0.794	0.64
0.797	0.333	0.801	0.461	0.793	0.569	0.786	0.642	0.803	0.622	0.803	0.621	0.794	0.64
0.797	0.333	0.801	0.462	0.783	0.584	0.786	0.642	0.786	0.644	0.787	0.642	0.777	0.661

17 Additional Information

17.1 Listing of related documents

Ref #	Document Kind, Title
[1]	VDE-AR-N 4105:2018-11
[2]	VDE-AR-N 4110:2018-11
[3]	IEC/TR 61850-90-7 Edition 1.0 2013-02
[4]	PQstorI grid code profile management 2.00 user manual